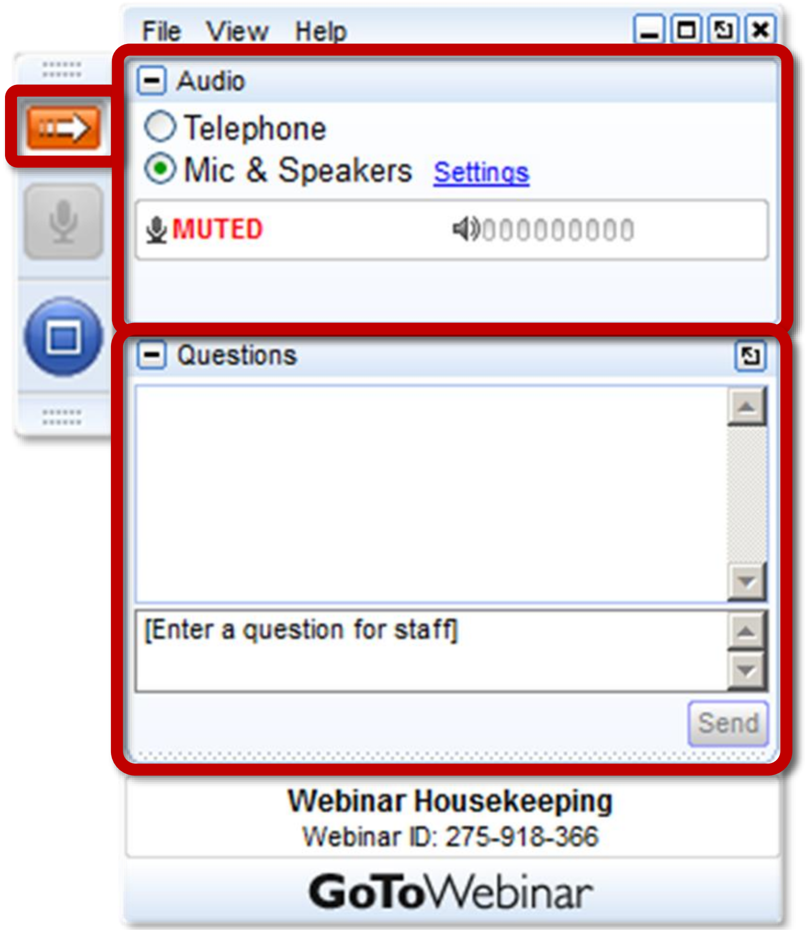
100% Clean Energy Collaborative Webinar

Decarbonizing Electricity: The Critical Role of Firm Low-Carbon Resources

May 15, 2020

Clean Energy States Alliance

Housekeeping



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Webinar Speakers

Jesse Jenkins
Assistant Professor,
Princeton University

PRINCETON UNIVERSITY

Warren Leon
Executive Director,
Clean Energy States Alliance
(moderator)

Clean Energy States Alliance

Decarbonizing Electricity

The Critical Role of Firm Low-Carbon Resources

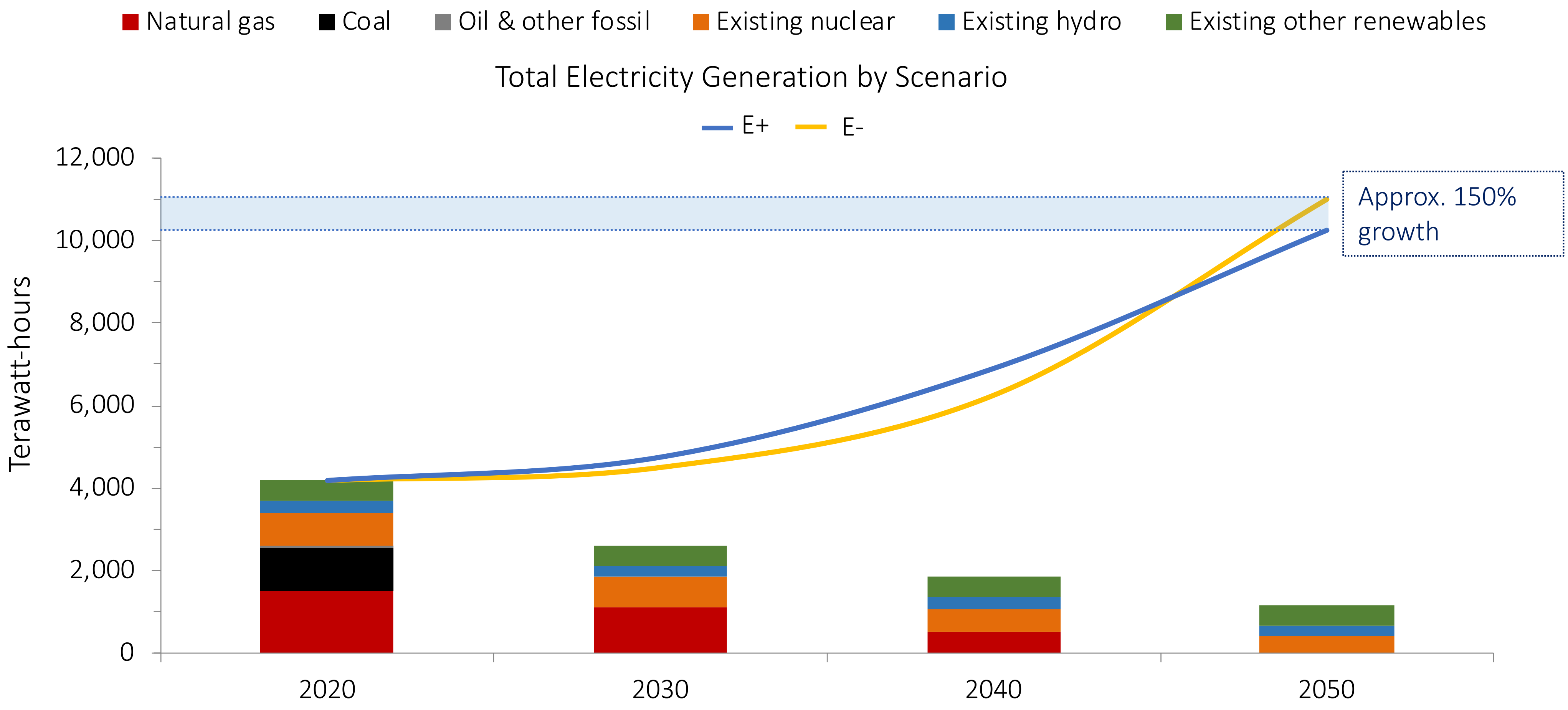
Jesse D. Jenkins, PhD

Assistant Professor | Princeton University

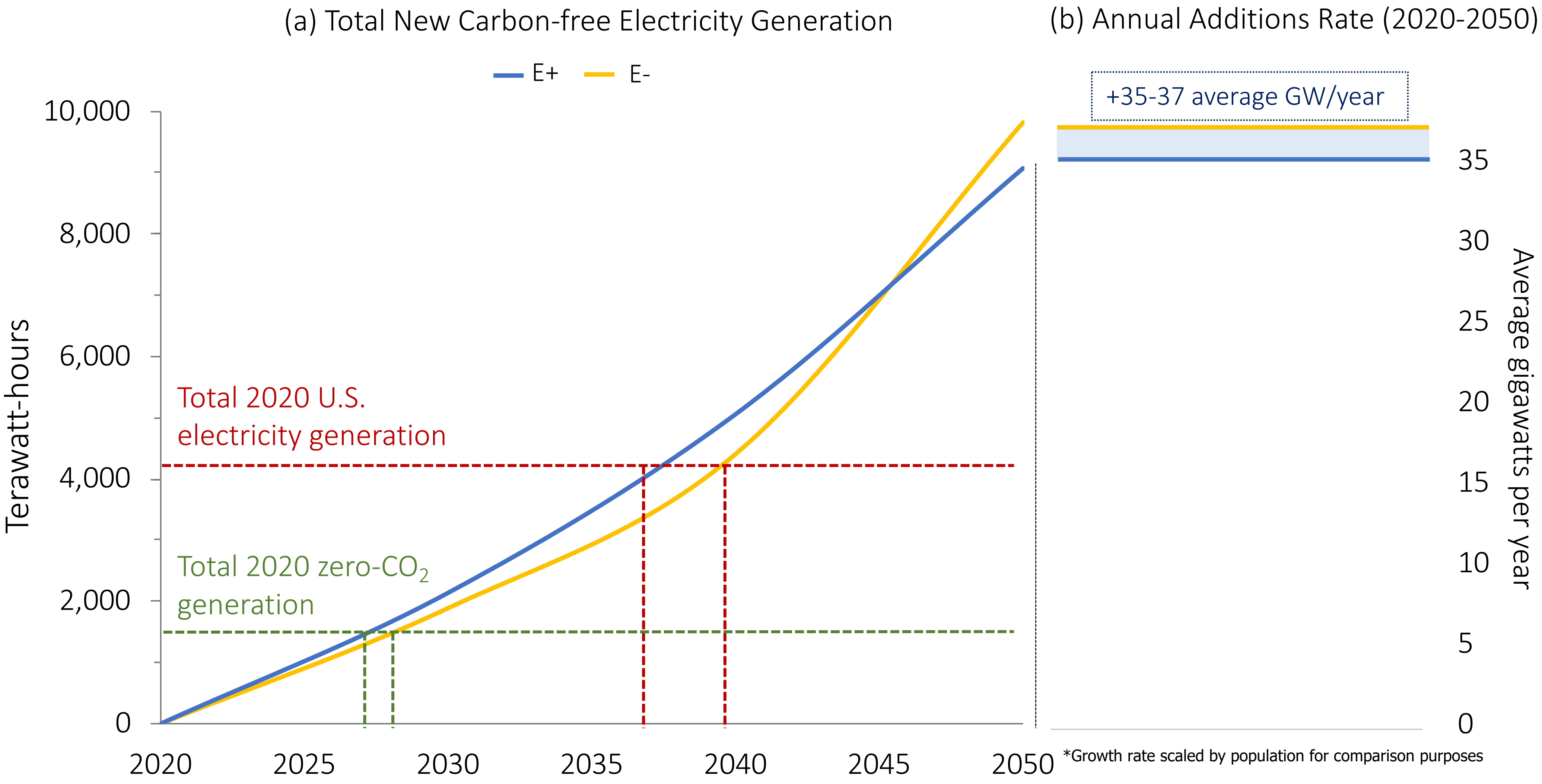
Dept. of Mechanical & Aerospace Engineering | Andlinger Center for Energy & Environment

Clean Energy States Alliance Webinar | May 15, 2020

Twin challenges: zero carbon, >double demand



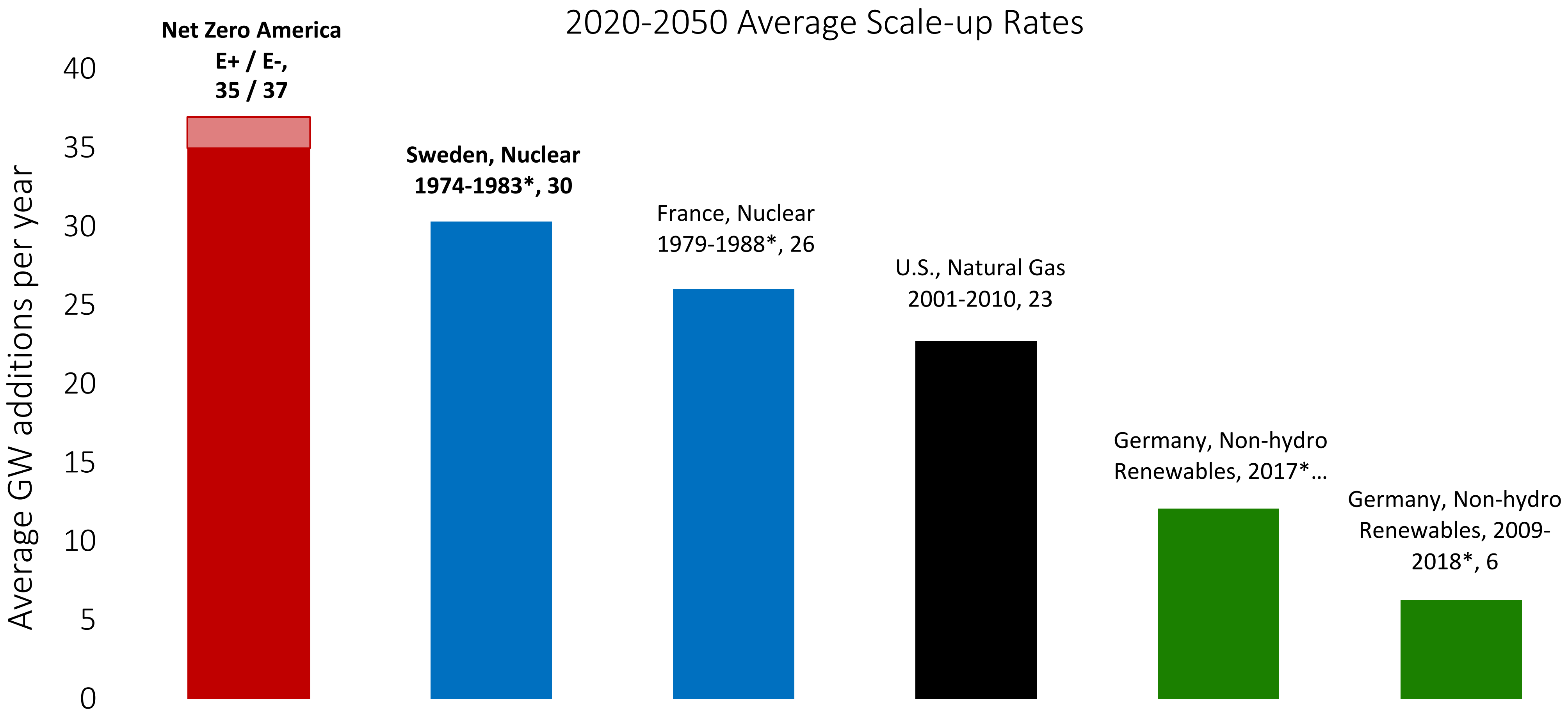
Data source: Preliminary results, Princeton University and Evolved Energy Research, *Net Zero America study*. Net zero greenhouse gas emissions by 2050 scenarios.



Data source: Preliminary results, Princeton University and Evolved Energy Research, *Net Zero America study.* Net zero greenhouse gas emissions by 2050 scenarios.

(b) Data source: U.S. EIA for renewables growth rate. MIT *Future of Nuclear in a Carbon Constrained World* study for historic nuclear growth rate (rescaled by population for comparison)

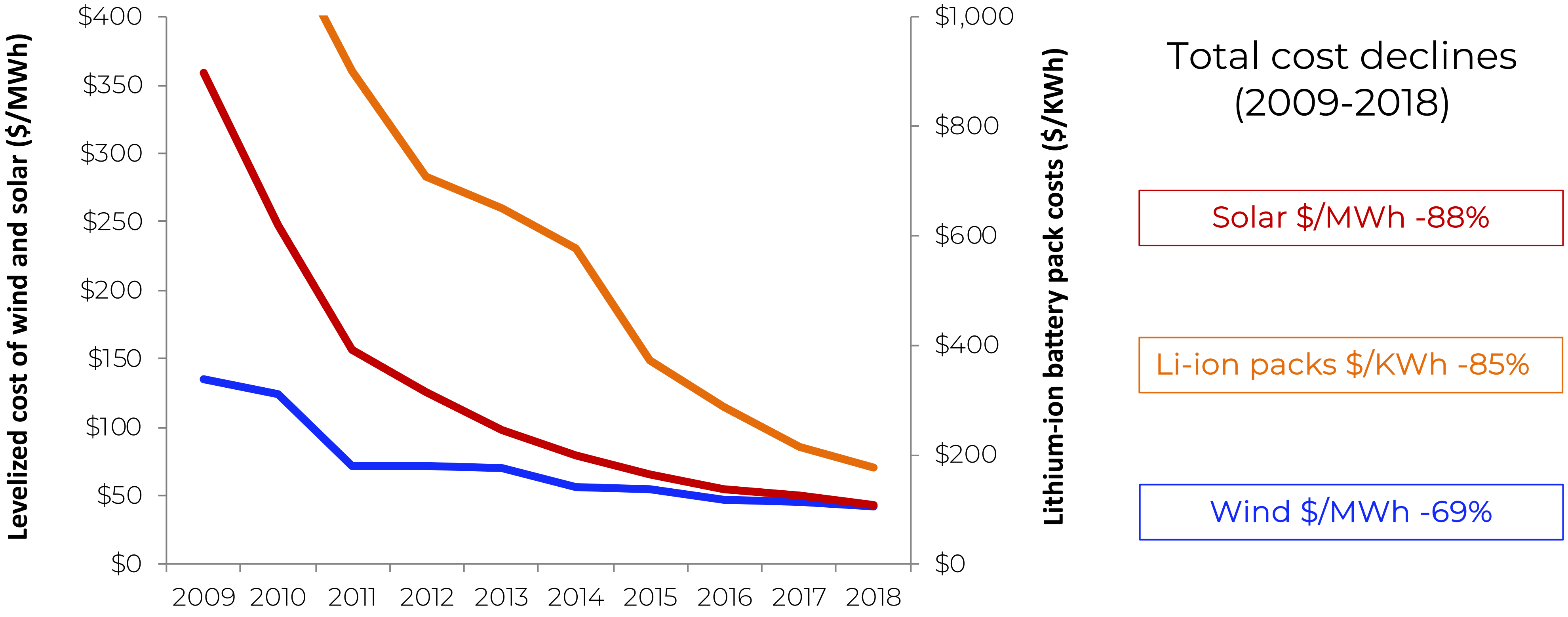
Clean electricity growth without precedent



*Growth rate scaled by population for comparison purposes

Data sources: U.S. renewables from Historical per capita deployment rates from MIT 2018, The Future of Nuclear in a Carbon Constrained World, scaled to based on projected 2035 U.S. population of 364 million from U.S. Census Bureau.

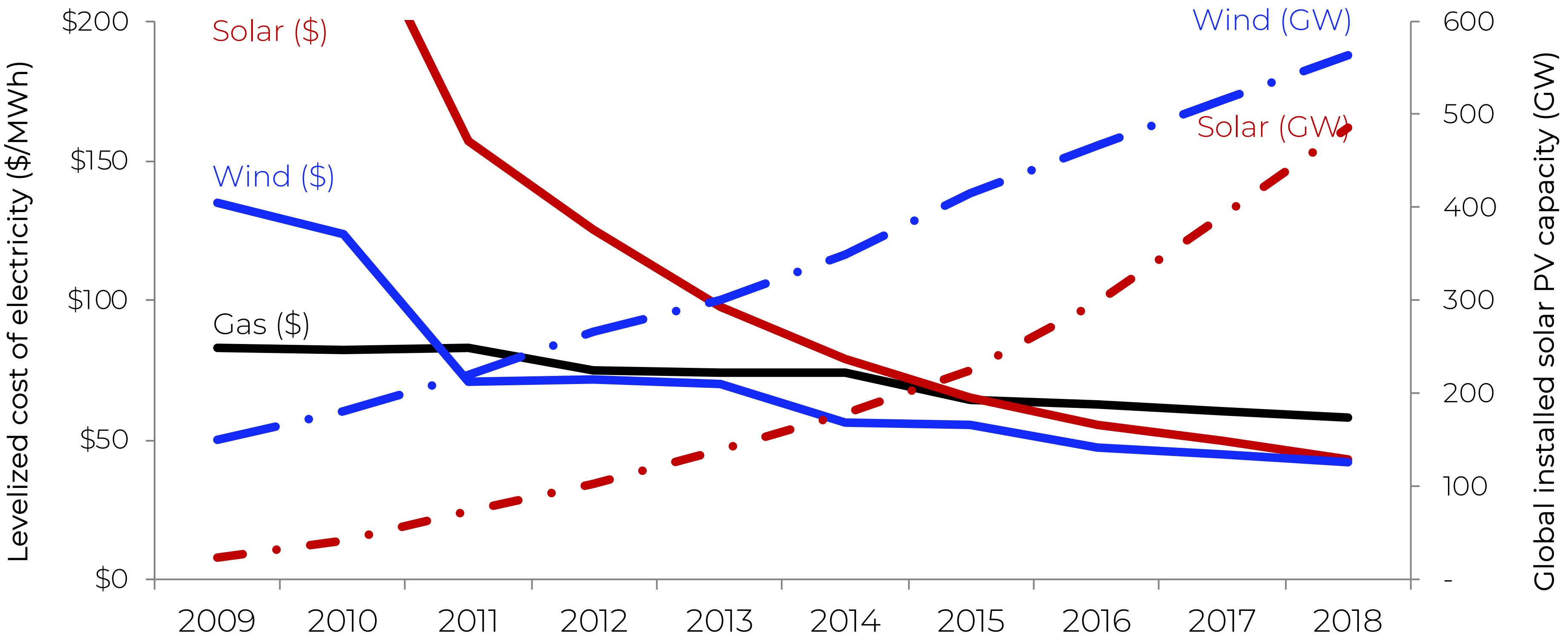
THE GOOD NEWS: WIND, SOLAR, BATTERY COSTS PLUMMET



Data Sources: Wind & solar costs from Lazard (2018), Lazard's Levelized Cost of Energy Analysis – Version 12.0, https://www.lazard.com/media/450784/lazards-levelized-cost-of-energy-version-120-vfinal.pdf/. Battery pack costs from Bloomberg New Energy Finance (2018), Battery Price Survey, https://about.bnef.com/blog/behind-scenes-take-lithium-ion-battery-prices/

THE LEVELIZED COST MENTAL MODEL

A race to beat fossil fuels on cost…



Data Sources: Costs from Lazard (2018), Lazard's Levelized Cost of Energy Analysis – Version 12.0, https://www.lazard.com/media/450784/lazards-levelized-cost-of-energy-version-120-vfinal.pdf/. Global renewable energy capacity from IRENA (2019), Renewable Energy Statistics 2019 https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Mar/IRENA_RE_Capacity_Statistics_2019.pdf

A riddle…

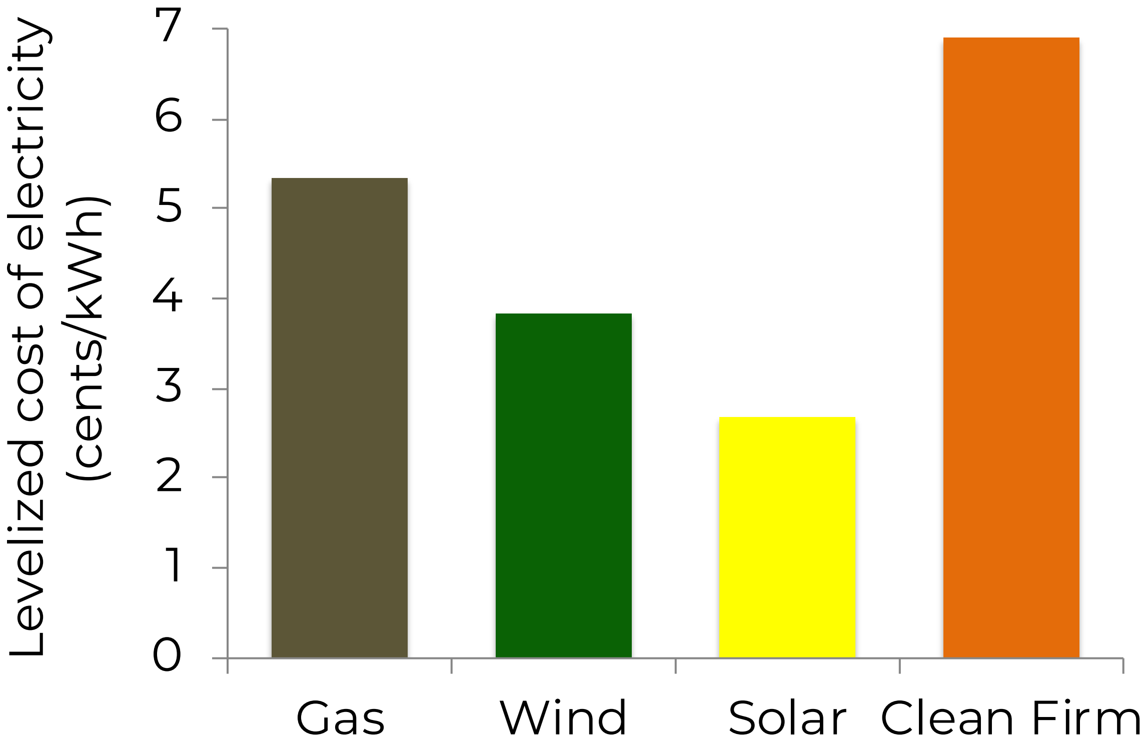
"It can be more expensive to add cheap solar than to add expensive geothermal."

-David Olsen, Member of CAISO Board of Governors, former President & CEO of Patagonia

https://www.utilitydive.com/news/geothermals-surprise-cheap-renewables-could-keep-states-from-achieving-cl/569807/

?

The answer…



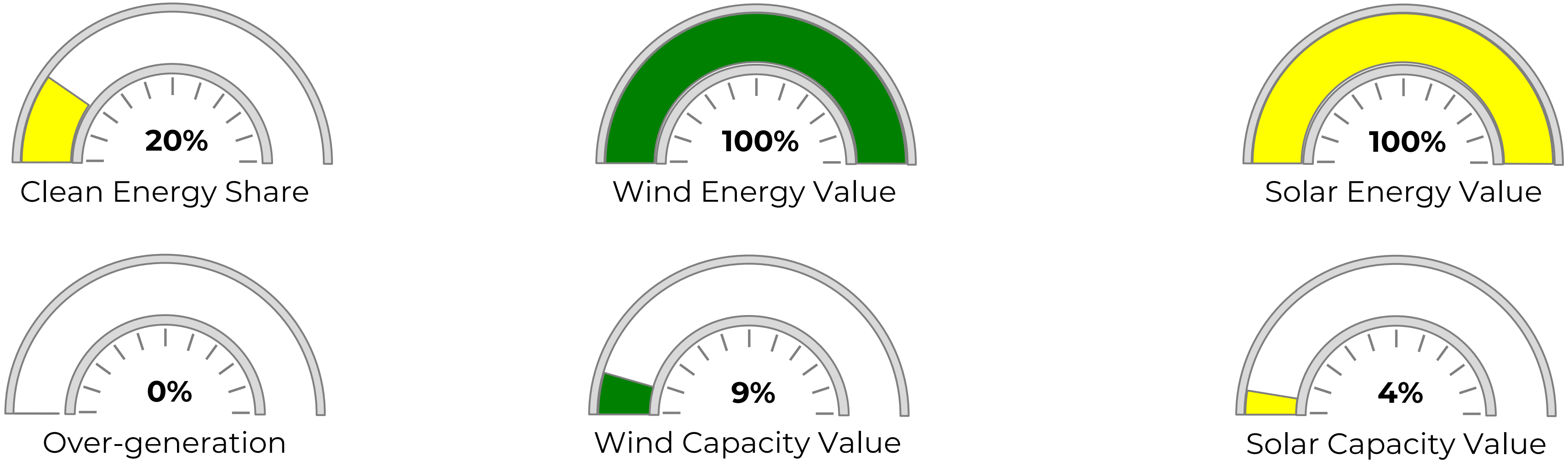
Peak demand: 34 GW

Capacity factors

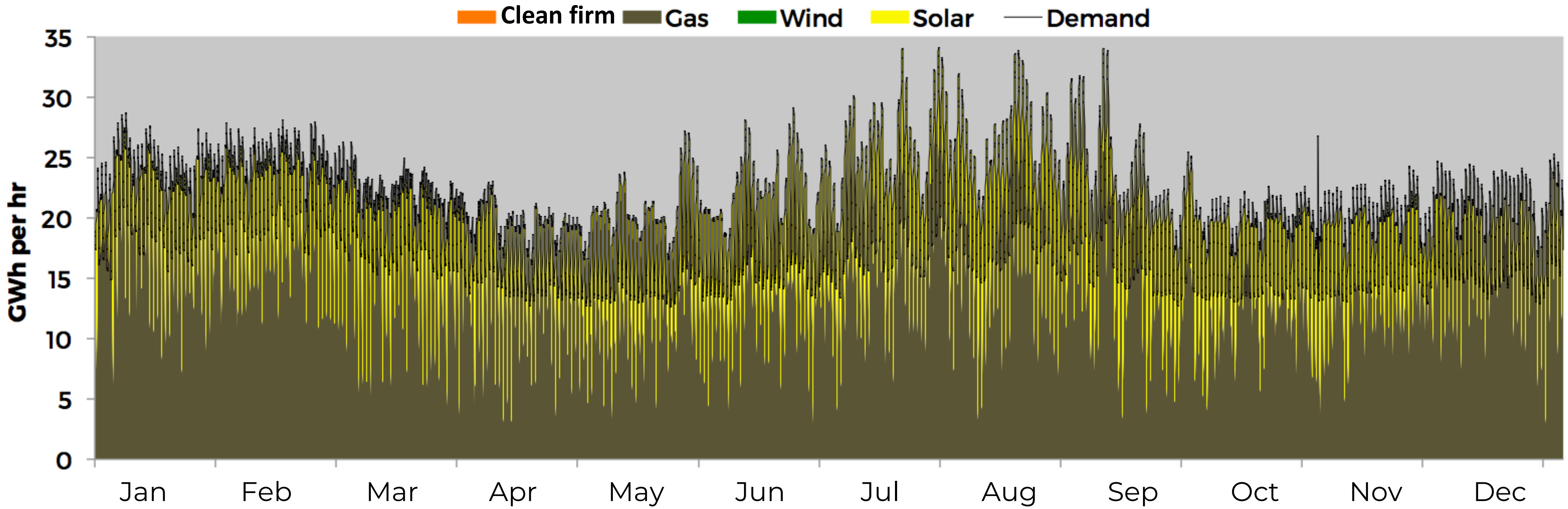
Wind: 28%

Solar: 24% (ac)

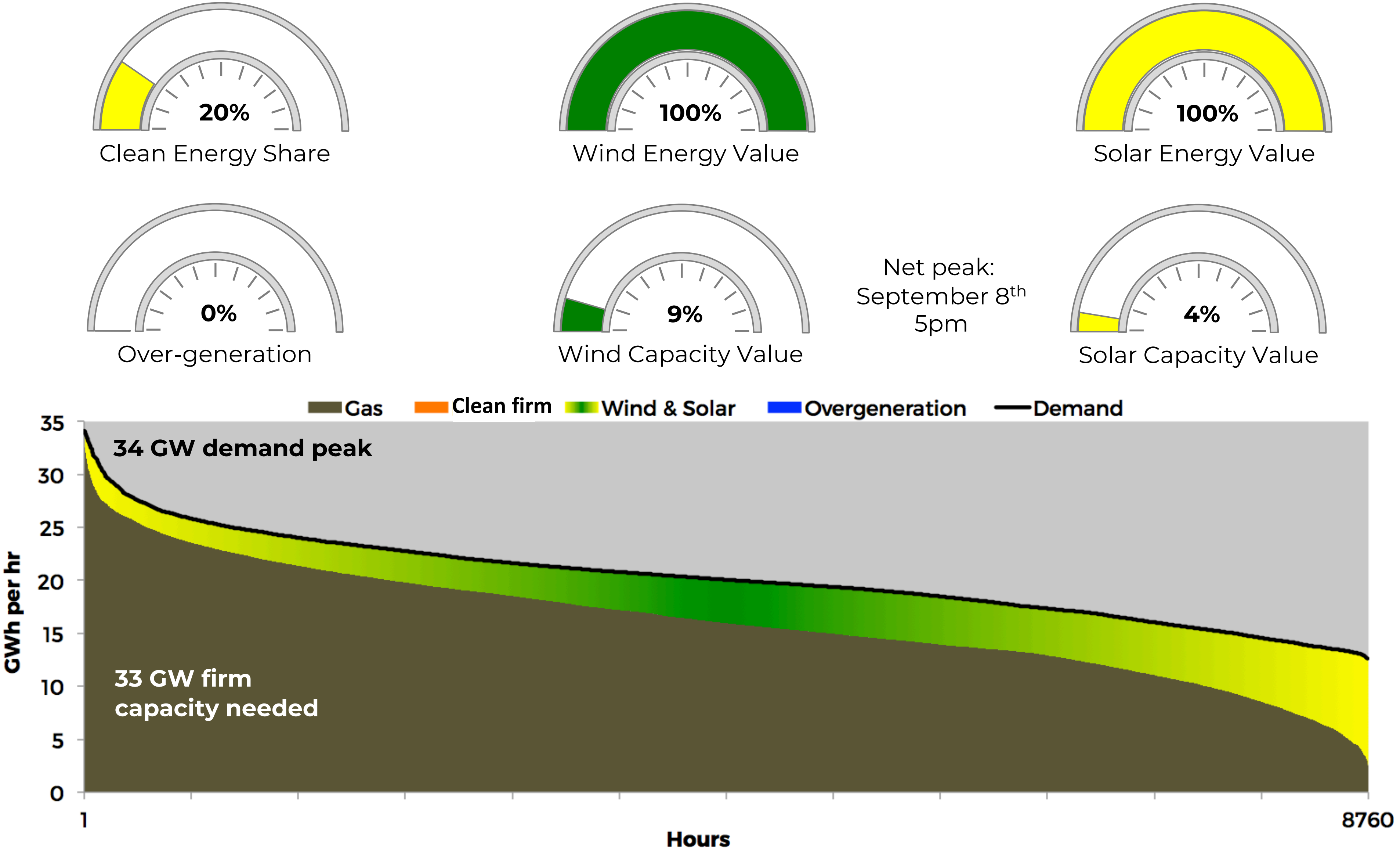
No storage in this example



20%
Clean Energy Share
100%
Wind Energy Value
100%
Solar Energy Value
0%
Over-generation
9%
Wind Capacity Value
4%
Solar Capacity Value



Clean firm
Gas
Wind
Solar
Demand
GWh per hr
35
30
25
20
15
10
5
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec


20%
Clean Energy Share
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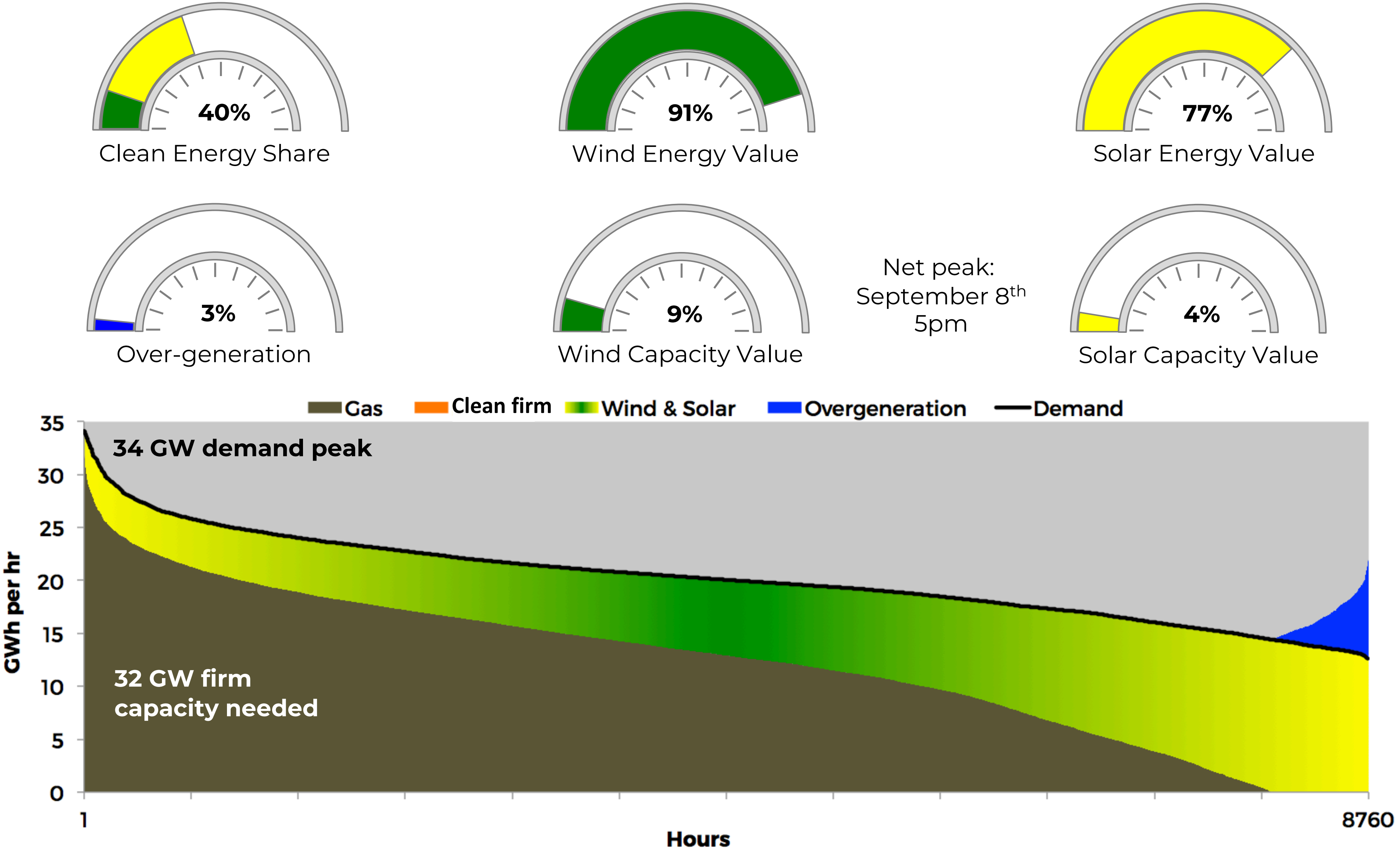
Wind Energy Value
100%
Solar Energy Value
0%
Over-generation
9%
Wind Capacity Value
Net peak:
September 8th
5pm
4%
Solar Capacity Value
Gas
Clean firm
Wind & Solar
Overgeneration
Demand
34 GW demand peak
33 GW firm
capacity needed
GWh per hr
35
30
25
20
15
10
5
0
1
8760
Hours


40%
Clean Energy Share
91%
Wind Energy Value
77%
Solar Energy Value
3%
Over-generation
9%
Wind Capacity Value
Net peak:
September 8th
5pm
4%
Solar Capacity Value
Gas
Clean firm
Wind & Solar
Overgeneration
Demand
34 GW demand peak
32 GW firm
capacity needed
GWh per hr
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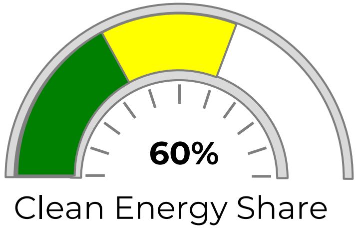
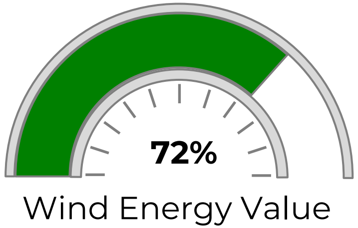
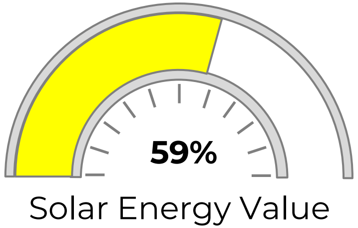
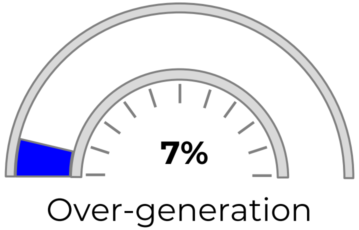
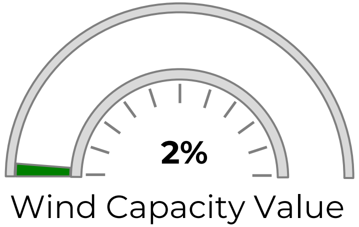
0
1
8760
Hours



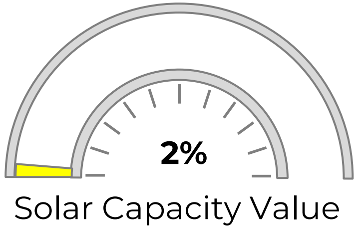


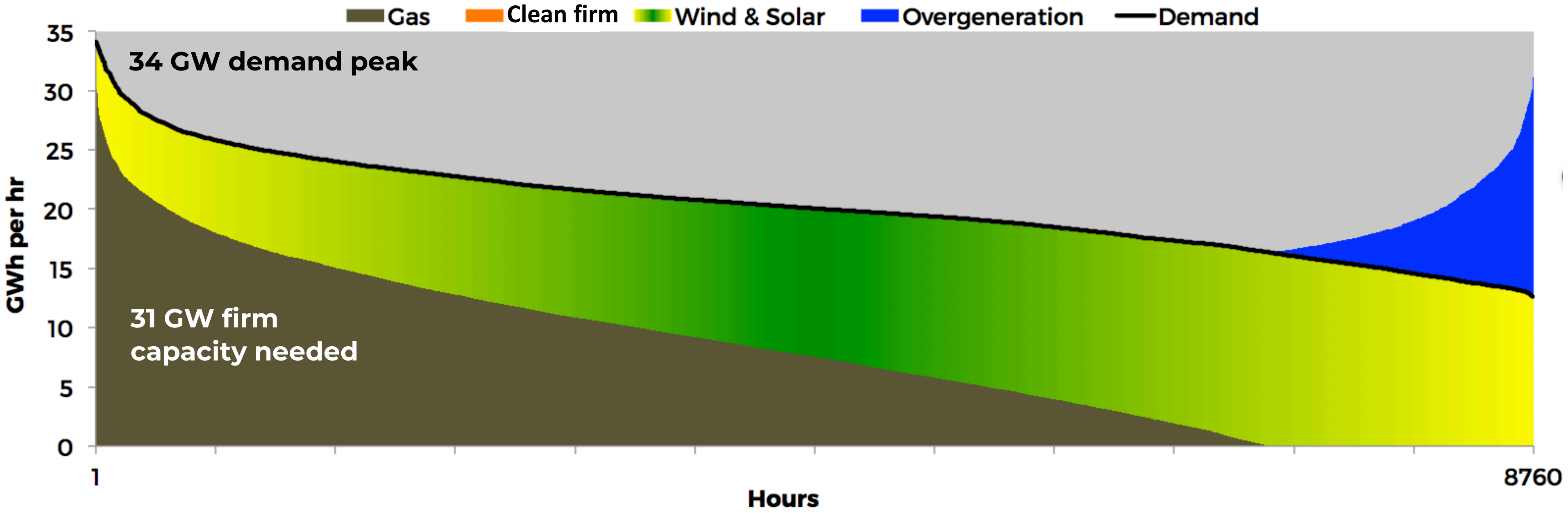


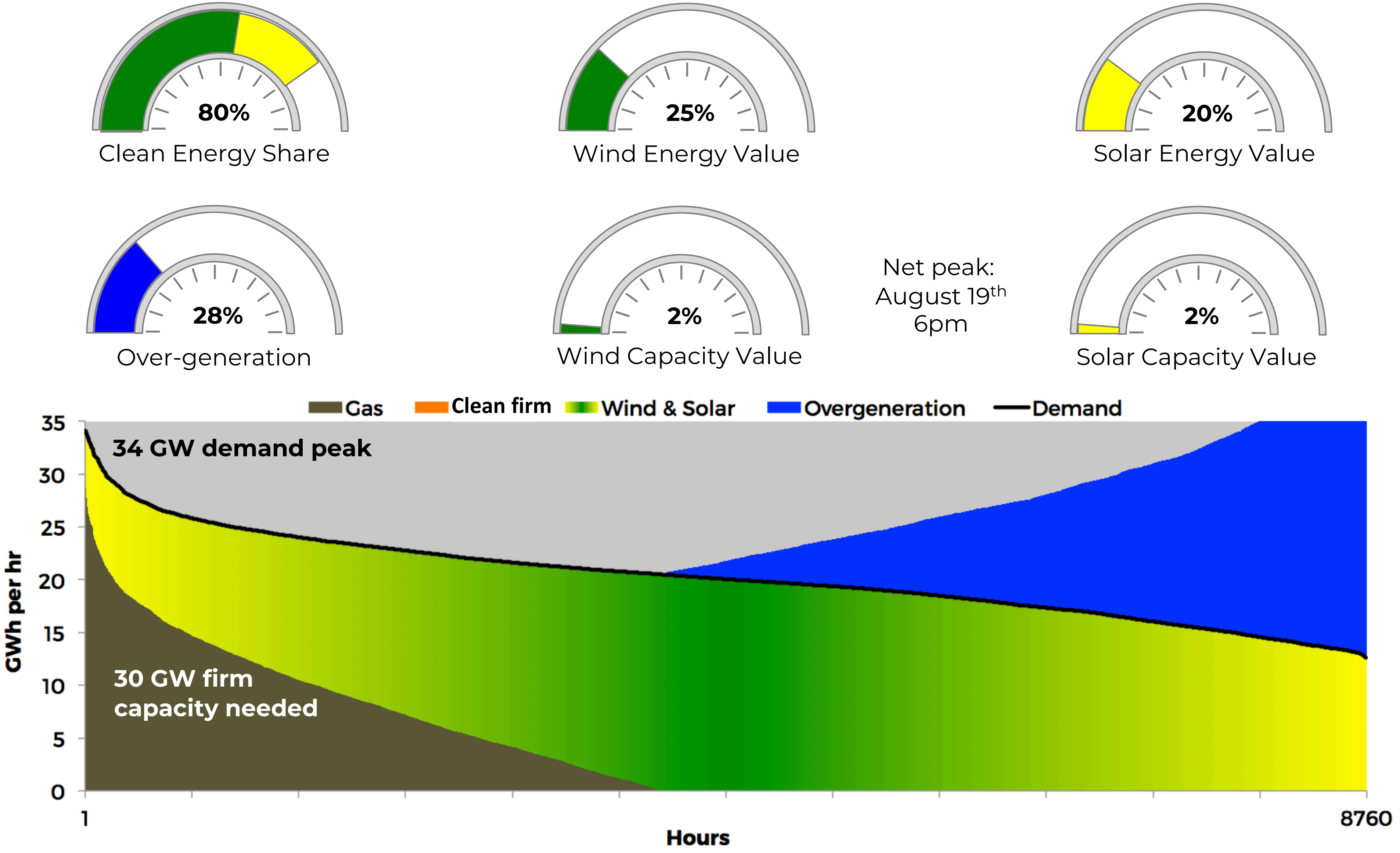




Net peak:
August 19th
6pm



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Clean Energy Share
25%
Wind Energy Value
20%
Solar Energy Value
28%
Over-generation
2%
Wind Capacity Value
Net peak:
August 19th
6pm
2%
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Gas
Clean firm
Wind & Solar
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Demand
34 GW demand peak
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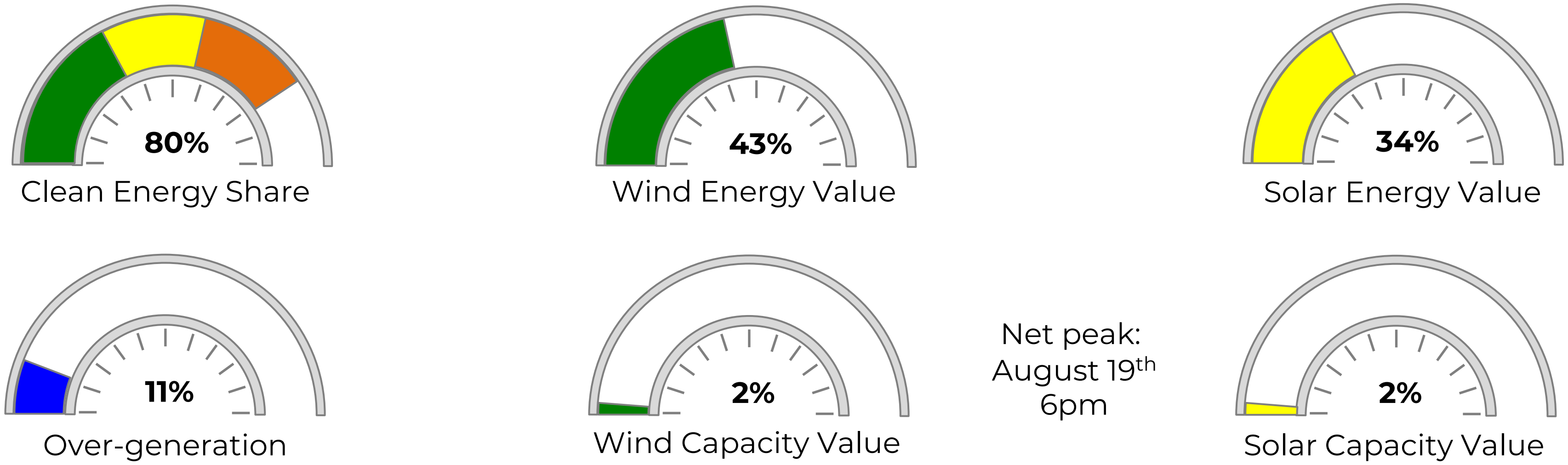
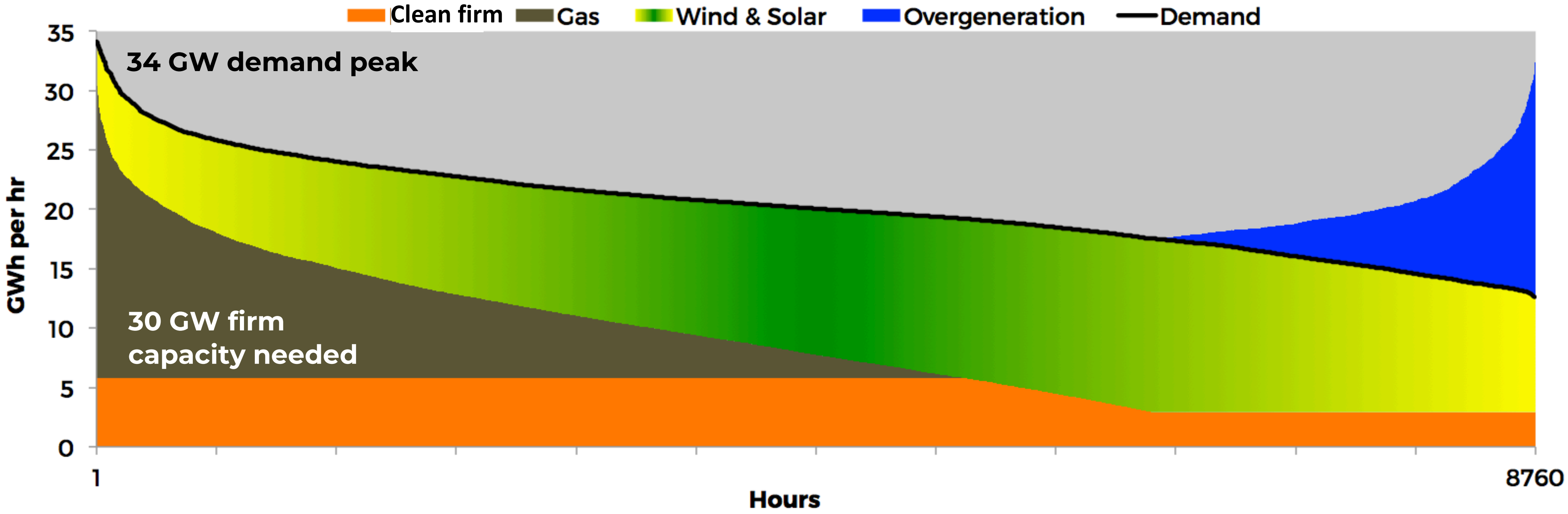

80%
Clean Energy Share
43%
Wind Energy Value
34%
Solar Energy Value
11%
Over-generation
2%
Wind Capacity Value
Net peak:
August 19th
6pm
2%
Solar Capacity Value


Clean firm
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Overgeneration
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capacity needed
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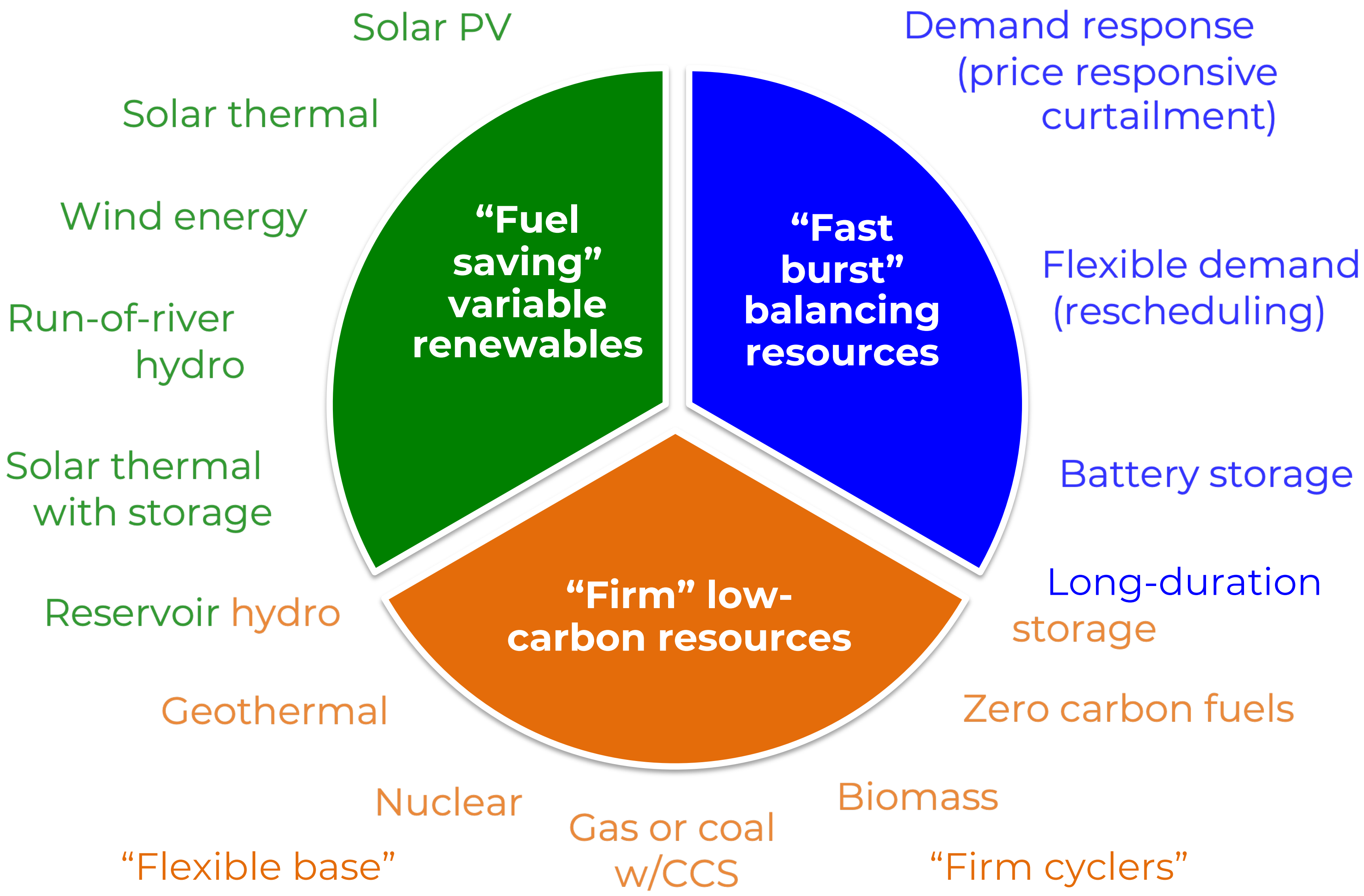
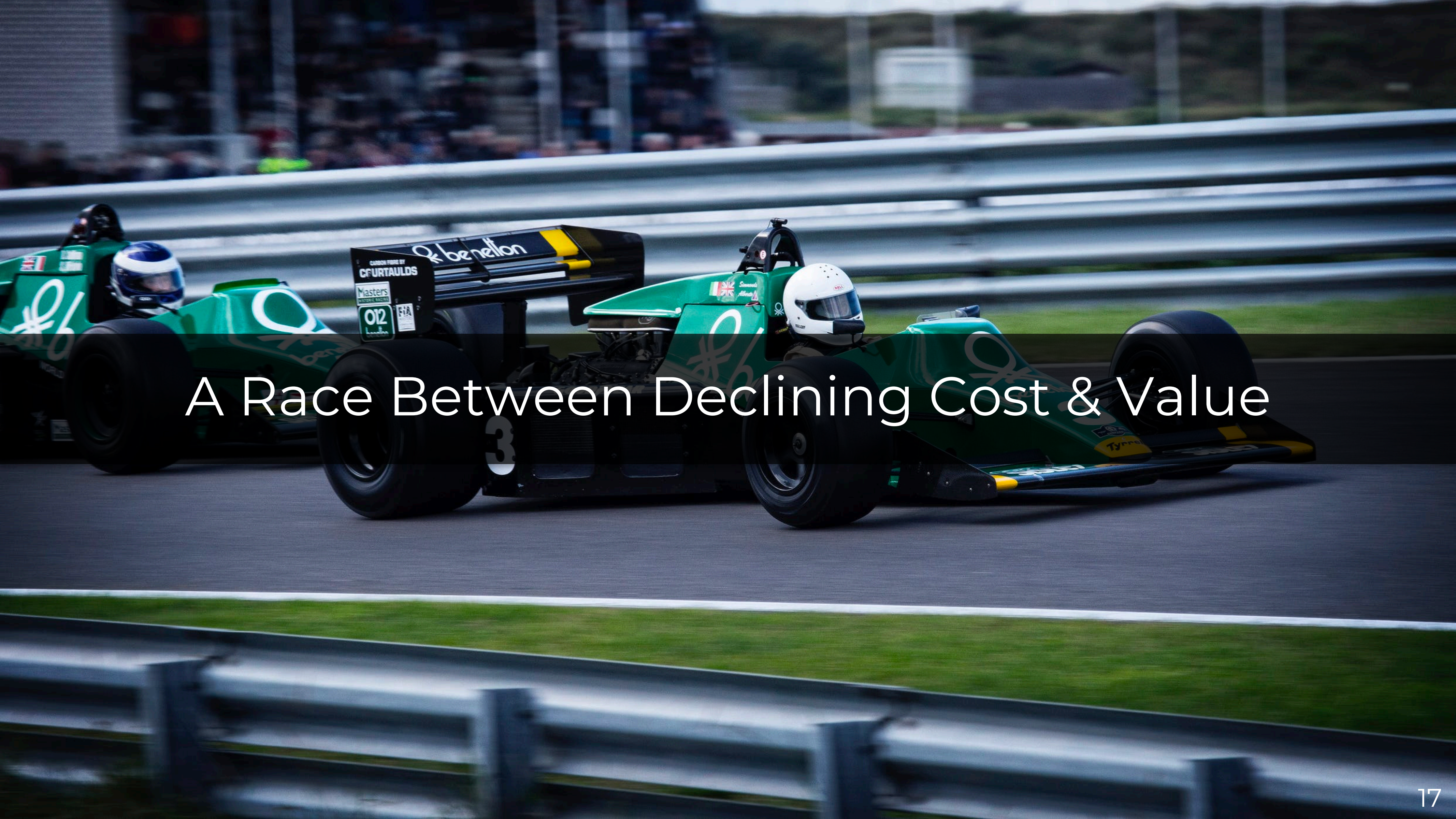
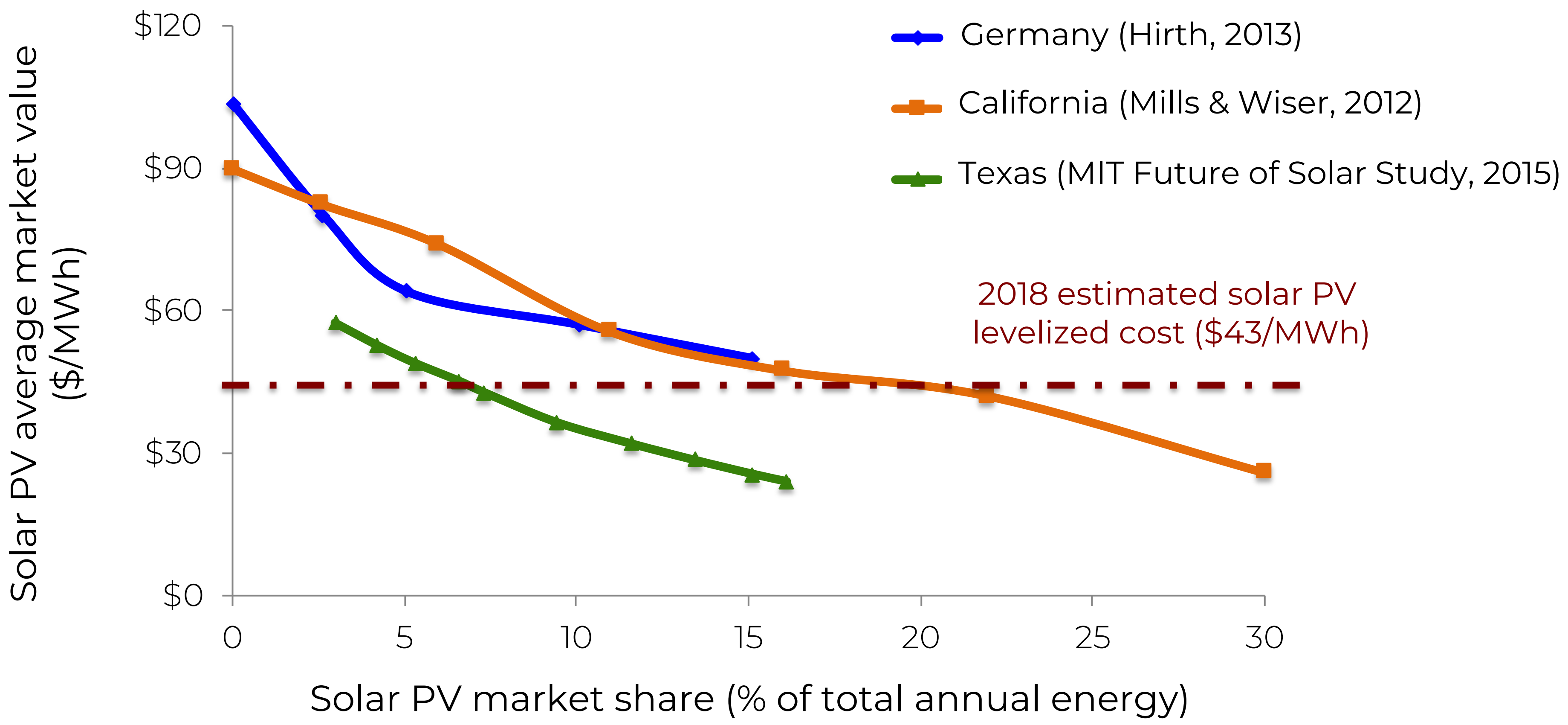


Solar PV
Solar thermal
Wind energy
Run-of-river hydro
Solar thermal with storage
Reservoir hydro
“Fuel saving” variable renewables
Demand response (price responsive curtailment)
Flexible demand (rescheduling)
Battery storage
Long-duration storage
“Fast burst” balancing resources
“Firm” low-carbon resources
Geothermal
Nuclear
Gas or coal w/CCS
Biomass
Zero carbon fuels
“Flexible base”
“Firm cyclers”



A Race Between Declining Cost & Value

A RACE AGAINST DECLINING VALUE (SOLAR PV)



Data Source: Sivaram & Kann (2016), Solar needs a more ambitious cost target, *Nature Energy* Vol. 1 (April 2016).
Solar cost estimate for 2018 from Lazard (2018) op. cit. above.

WIND/SOLAR VALUE DECLINE: KEY MECHANISMS

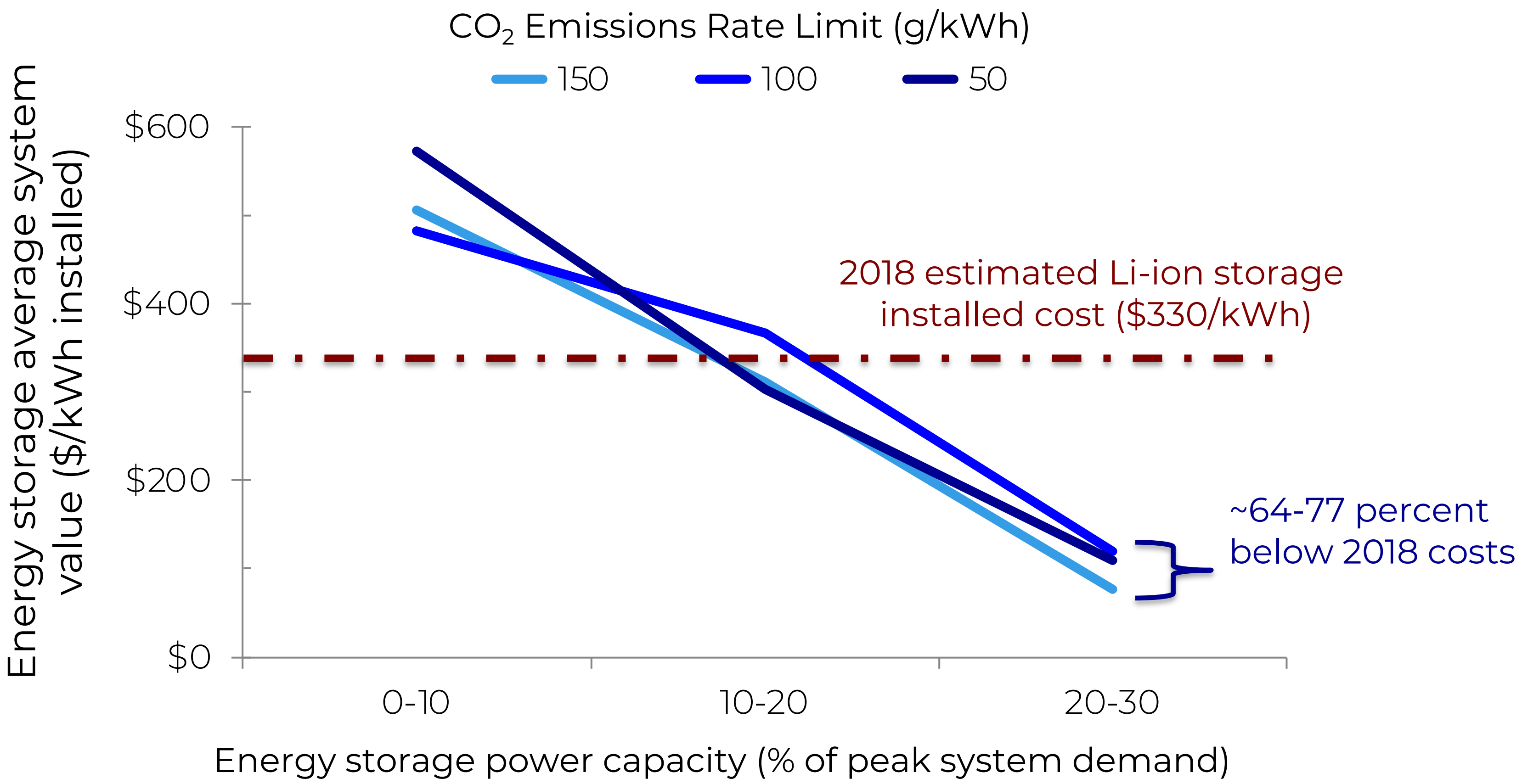
1. Declining “fuel-saving” value (energy substitution)

2. Decreasing “capacity value” (capacity substitution)

3. Increasing “over-generation” (energy that must be stored or wasted when supply exceeds demand)

Additional factors (aka “integration costs”):
Increasing flexibility, ramping and reserve requirements; thermal plant cycling costs; transmission network costs

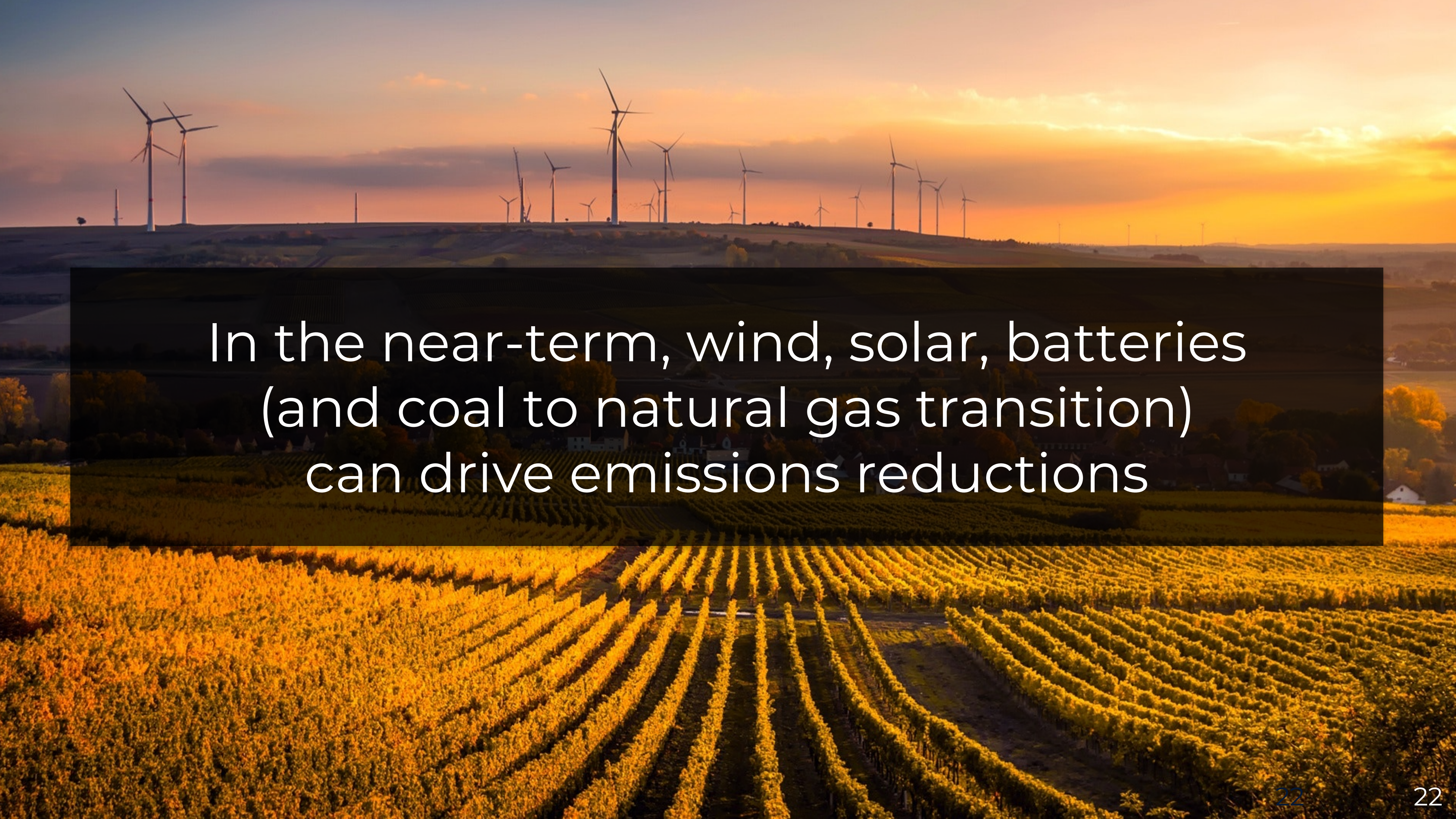
A RACE AGAINST DECLINING VALUE (ENERGY STORAGE)



Graphic is author's own created with data from: de Sisternes, Jenkins & Botterud (2016), "The value of energy storage in decarbonizing the electricity sector," *Applied Energy* 175: 368-379. Assumes Li-ion storage system with 2 hours storage duration and 10 year asset life. Estimated 2018 Li-ion storage cost per kWh from Lazard (2018), Lazard's Levelized Cost of Storage Analysis – Version 4.0.

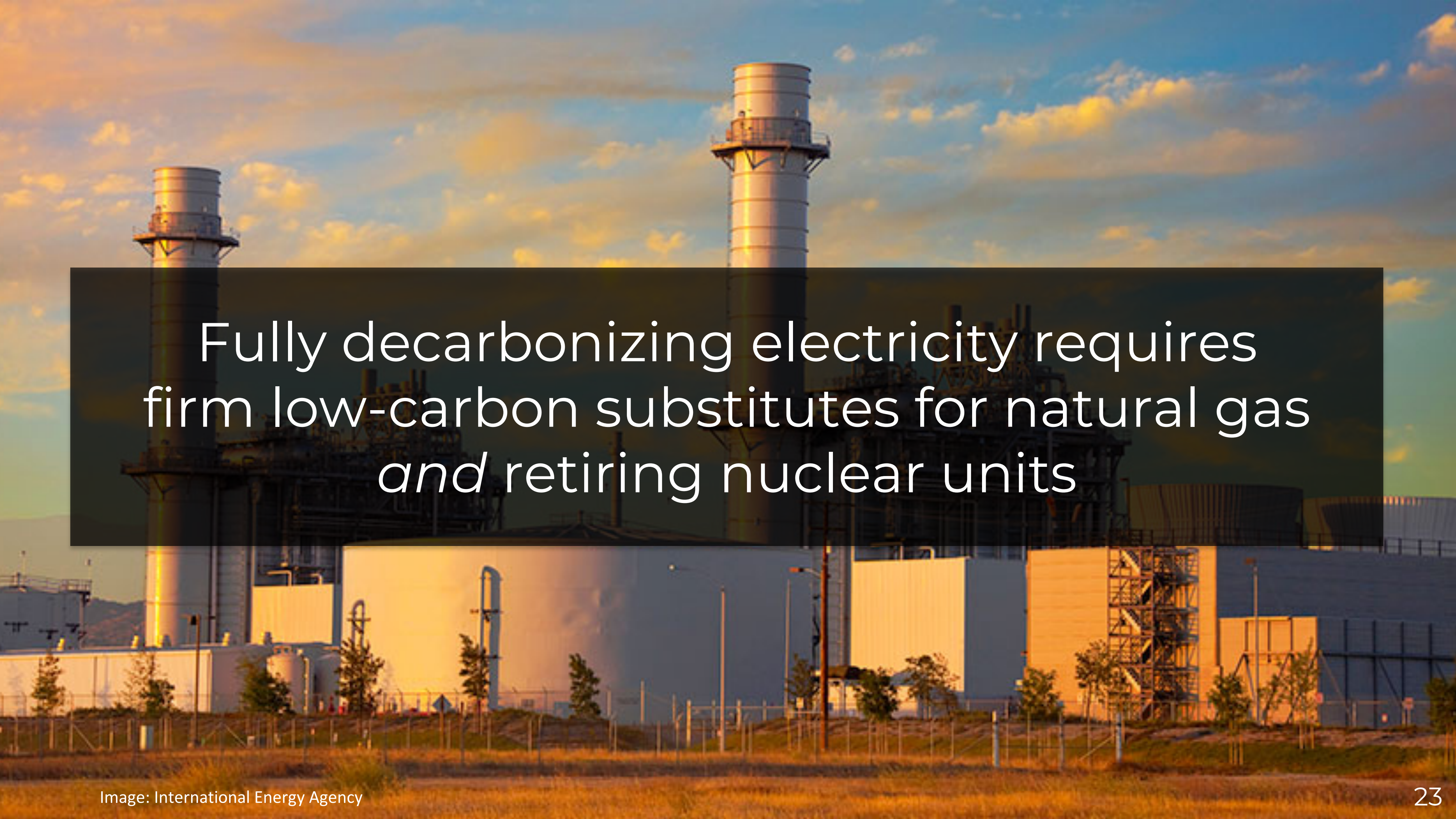
STORAGE VALUE DECLINE: KEY MECHANISMS

1. "Niche" markets fill quickly for regulation & reserves
2. Increasing energy storage (longer duration) needed to maintain capacity substitution value
3. Reduced energy arbitrage (buy-sell) spread
4. Declining utilization rate



In the near-term, wind, solar, batteries (and coal to natural gas transition) can drive emissions reductions

22



Fully decarbonizing electricity requires firm low-carbon substitutes for natural gas *and* retiring nuclear units

Image: International Energy Agency

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The Role of Firm Low-Carbon Electricity Resources in Deep Decarbonization of Power Generation

Nestor A. Sepulveda [4] • Jesse D. Jenkins • Fernando J. de Sisternes • Richard K. Lester •

Show footnotes

Published: September 06, 2018 • DOI: https://doi.org/10.1016/j.joule.2018.08.006

http://bit.ly/FirmLowCarbon

PlumX Metrics

Highlights

Summary

Graphical Abstract

Keywords

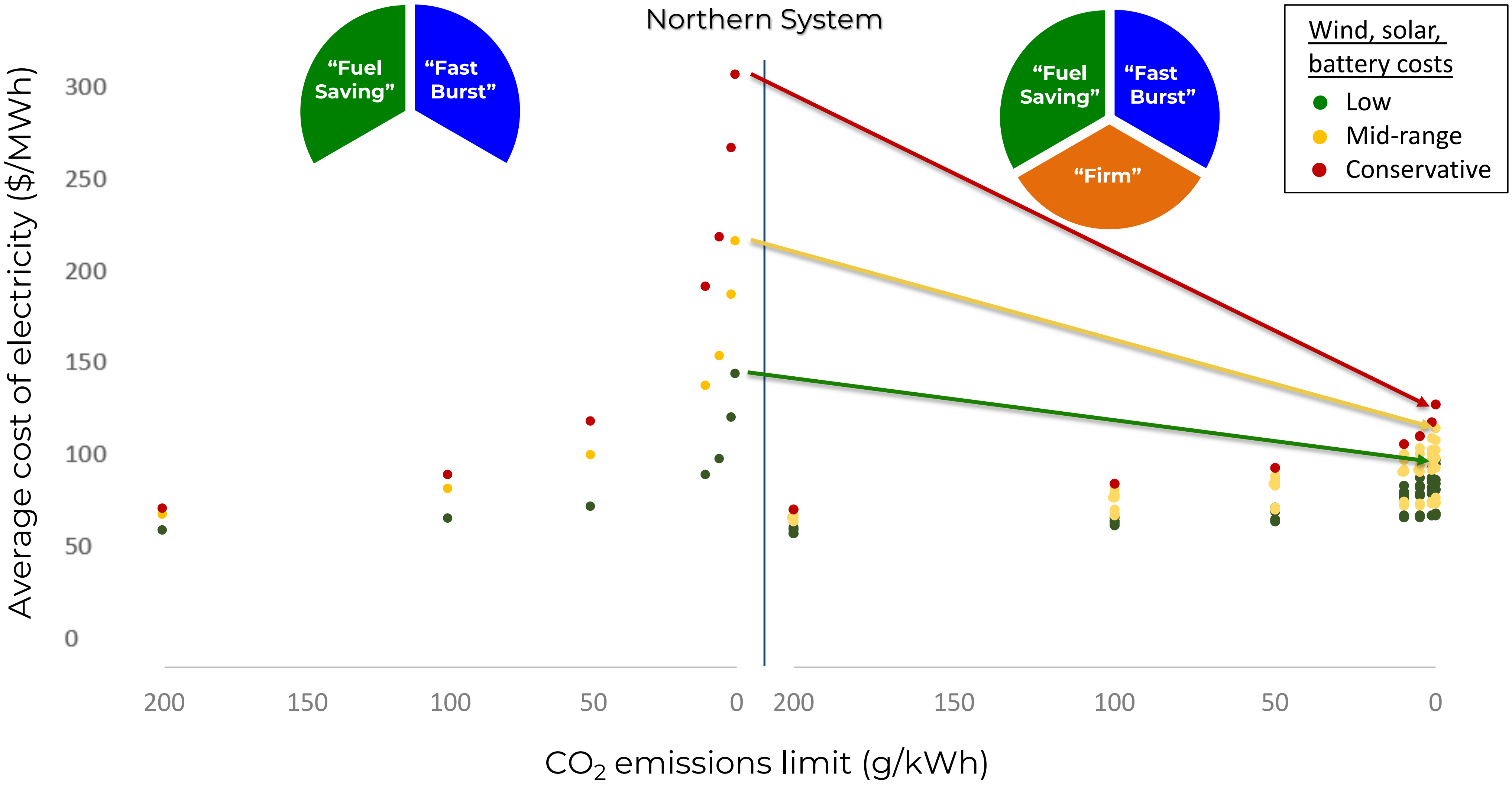
References

Article Info

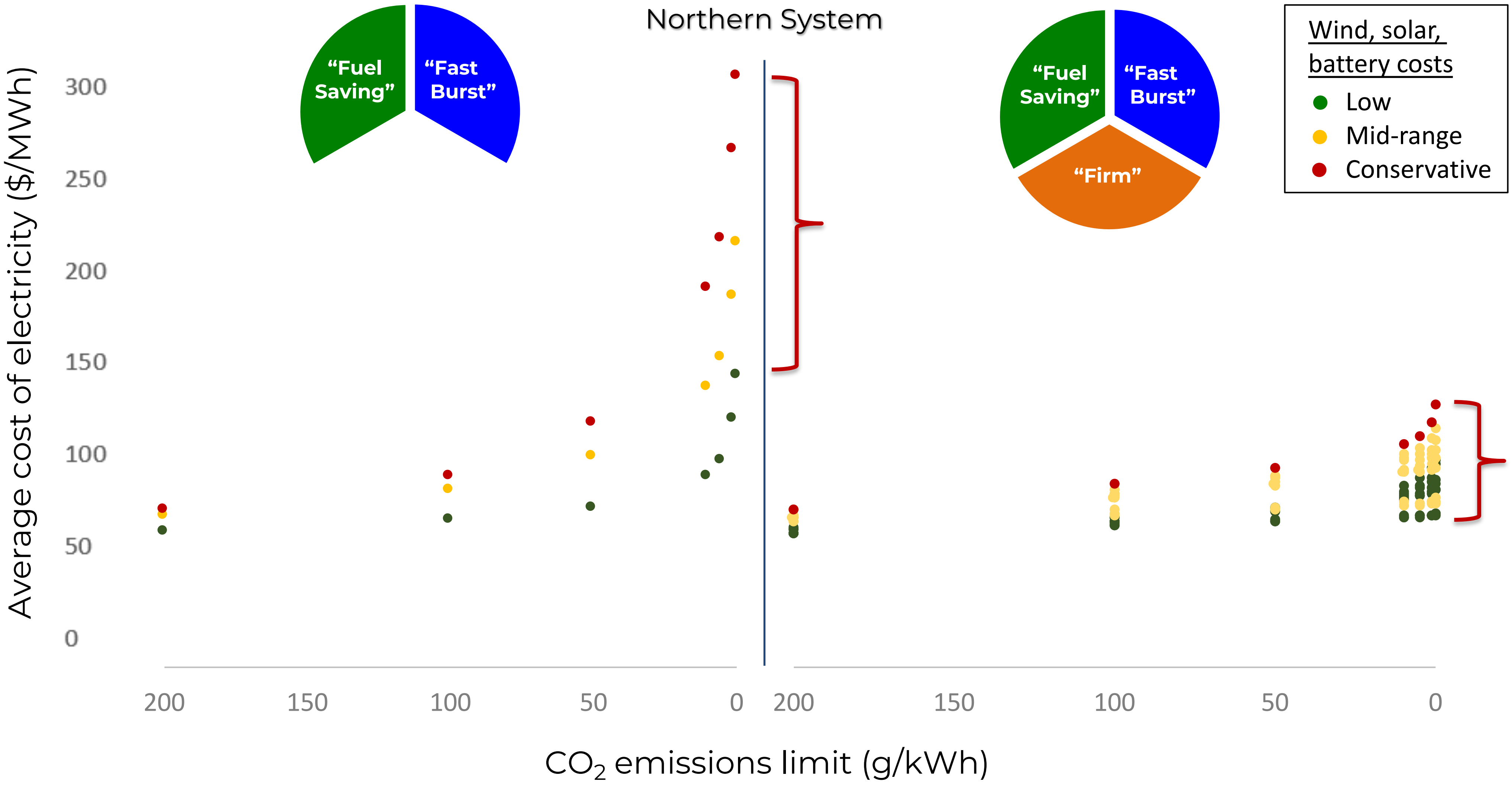
Highlights

- Firm low-carbon resources consistently lower decarbonized electricity system costs
- Availability of firm low-carbon resources reduces costs 10%–62% in zero-CO_2 cases
- Without these resources, electricity costs rise rapidly as CO_2 limits near zero

Recommend *Joule* to Your Librarian



Data source: Sepulveda, N., Jenkins, J.D., et al. (2018), "The role of firm low-carbon resources in deep decarbonization of electric power systems," *Joule* 2(11).



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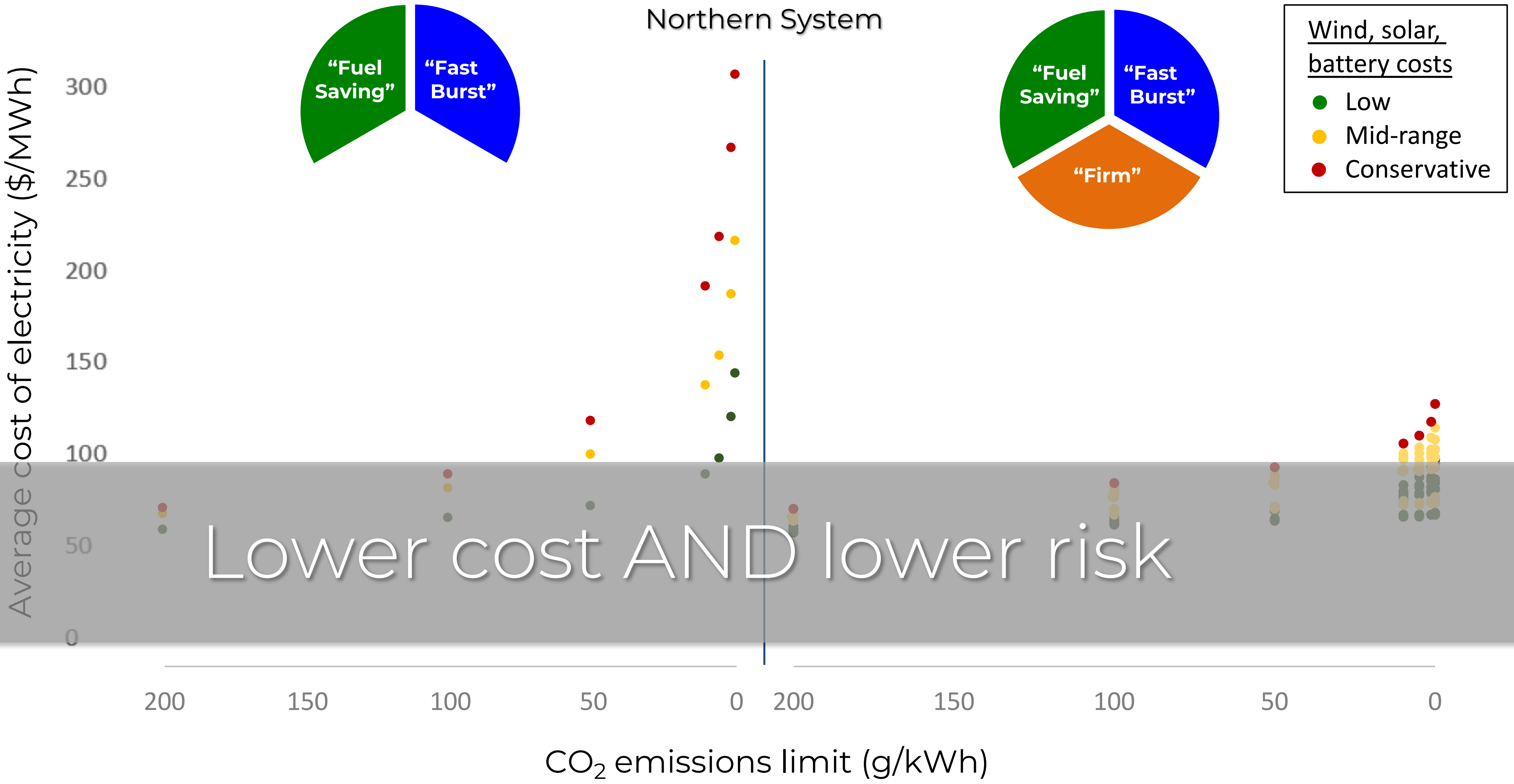
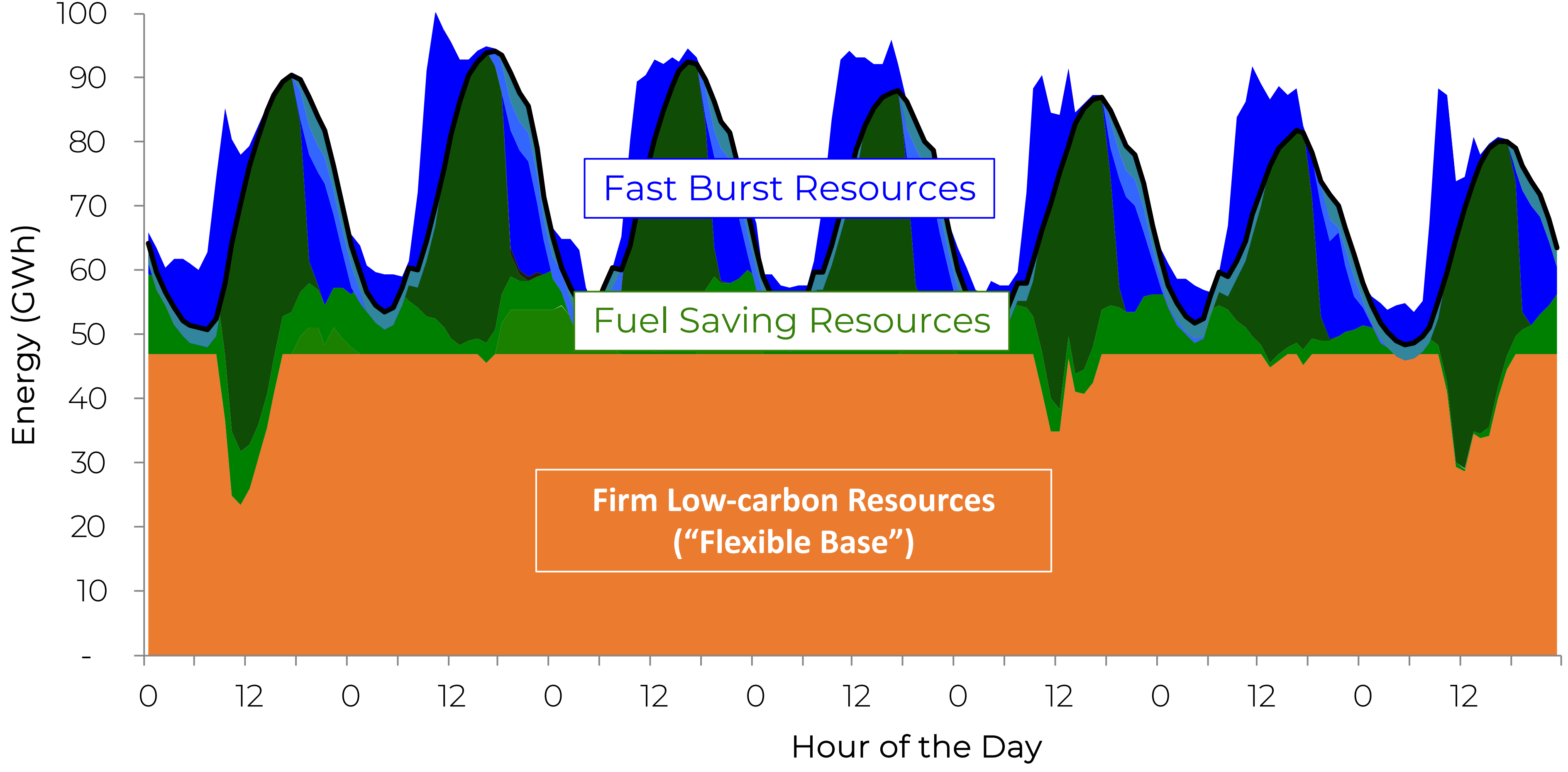


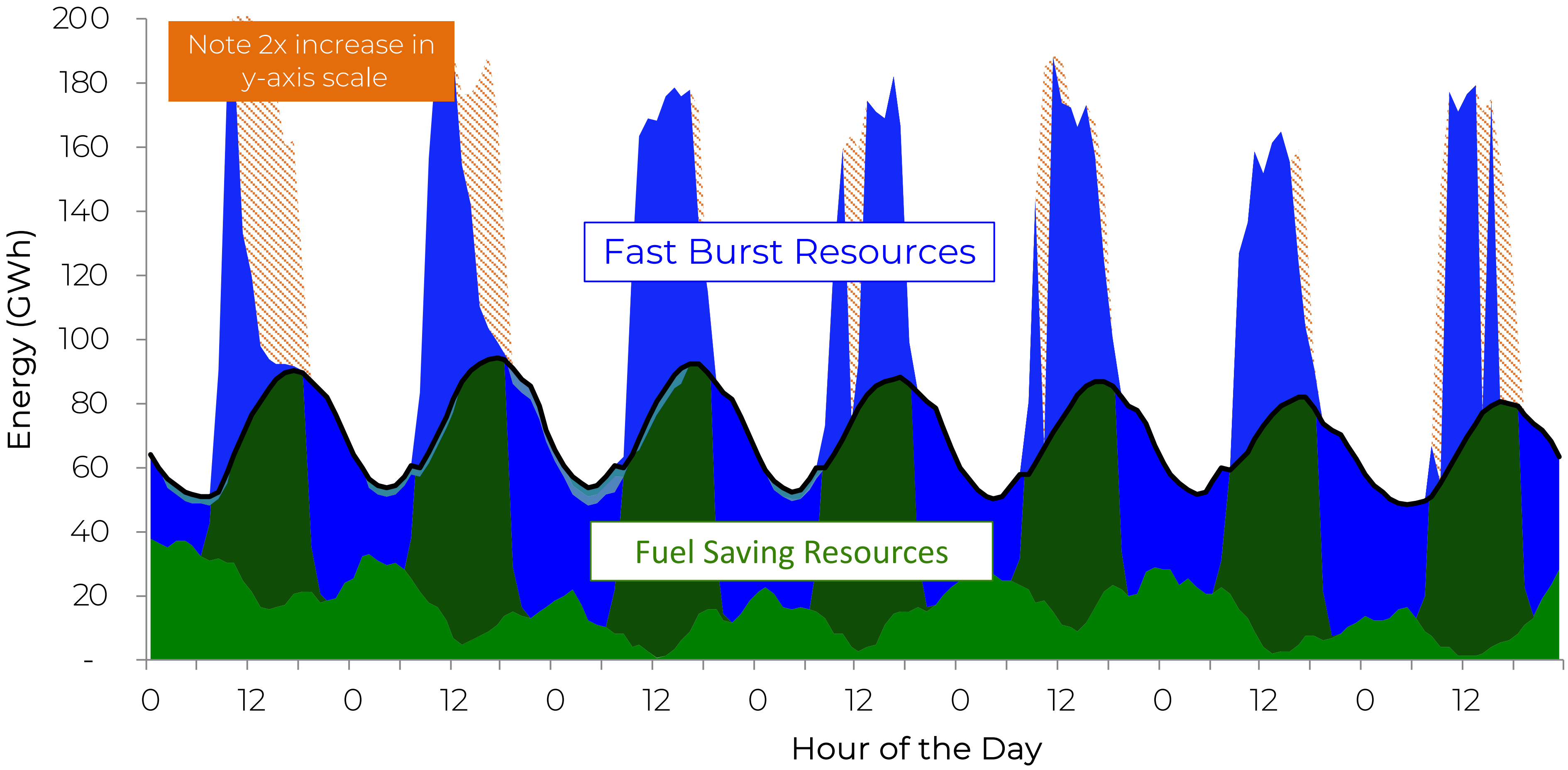
Lower cost AND lower risk

Data source: Sepulveda, N., Jenkins, J.D., et al. (2018), "The role of firm low-carbon resources in deep decarbonization of electric power systems," *Joule* 2(11).

One Possible Balanced Portfolio

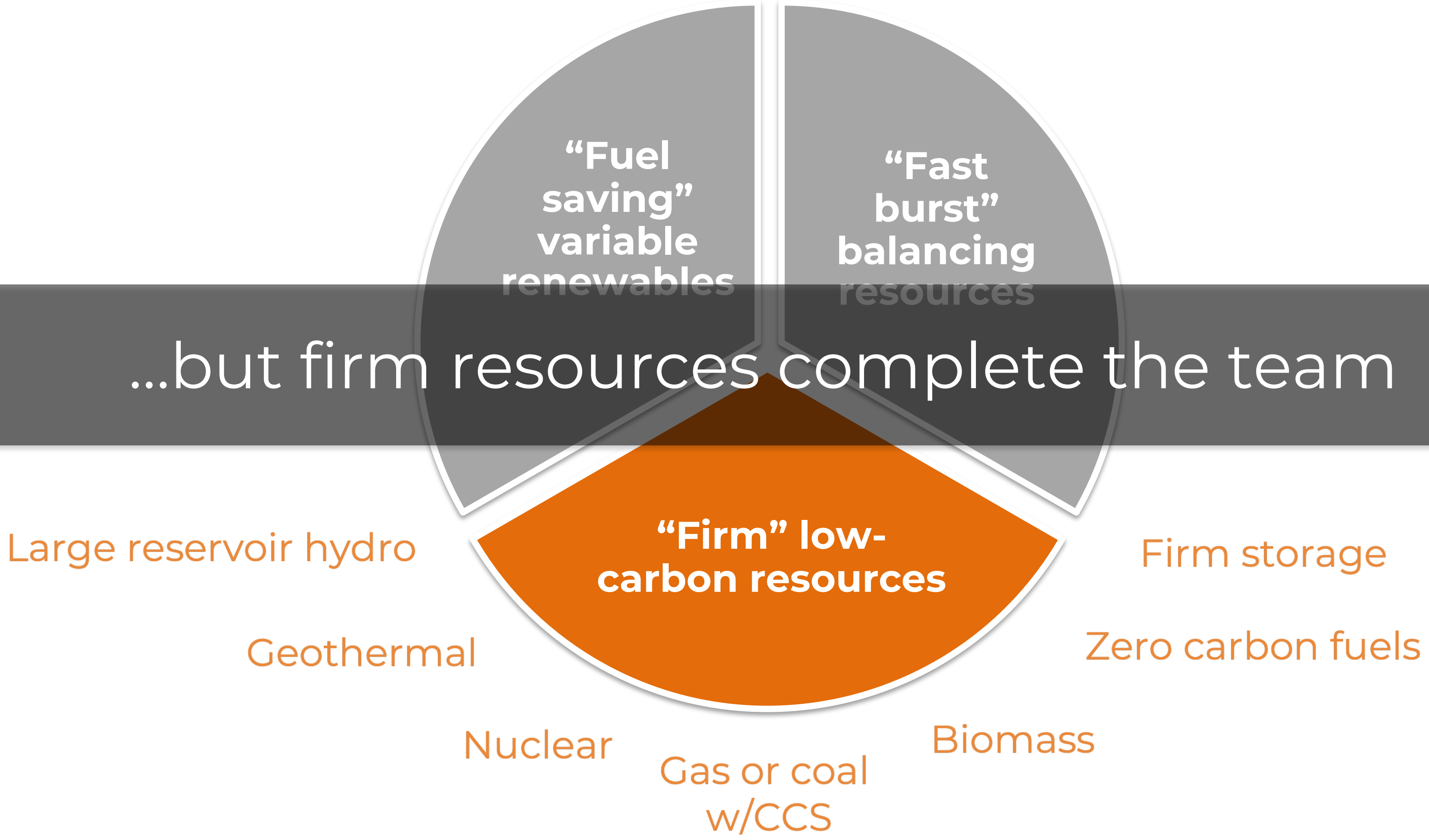


Without Firm Low-Carbon Resources




PRINCETON
2
Solar, wind & batteries will be stars...

…but firm resources complete the team



Nuclear Reactors

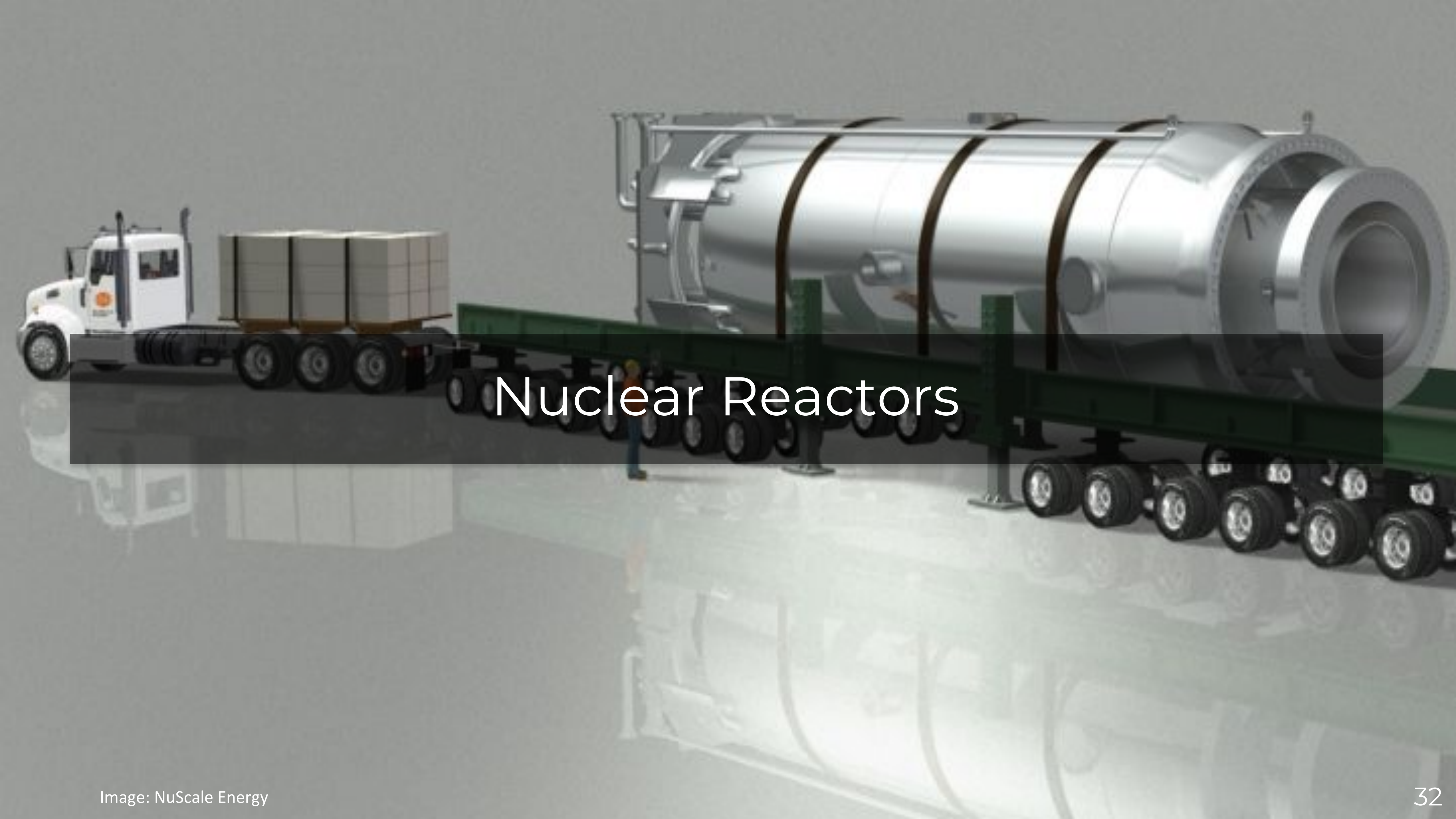


Image: NuScale Energy

Carbon Capture and Storage

Photo: NET Power

Zero Carbon Fuels

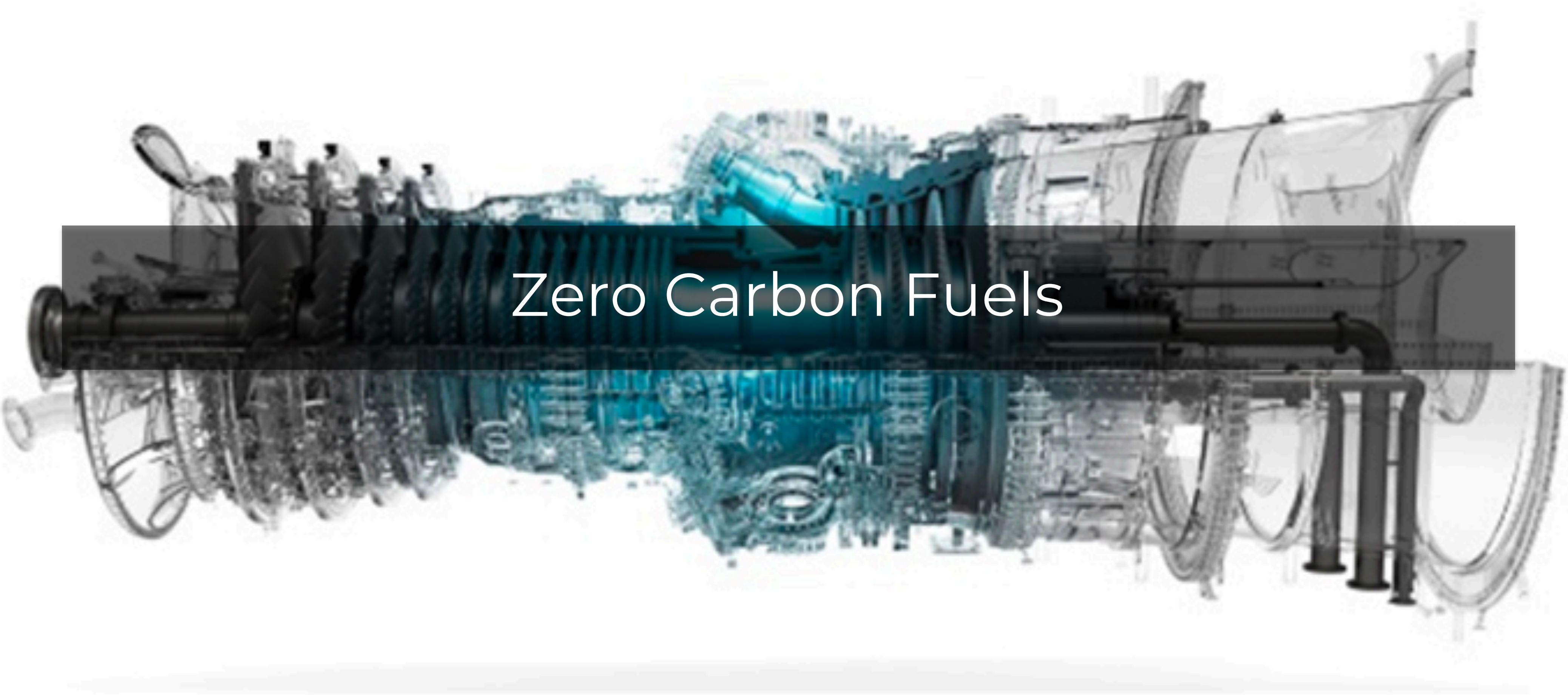


Image: Mitsubishi Heavy Industries

Hydropower with Large Reservoirs

Image: Hydro Quebec

Enhanced Geothermal Energy Systems

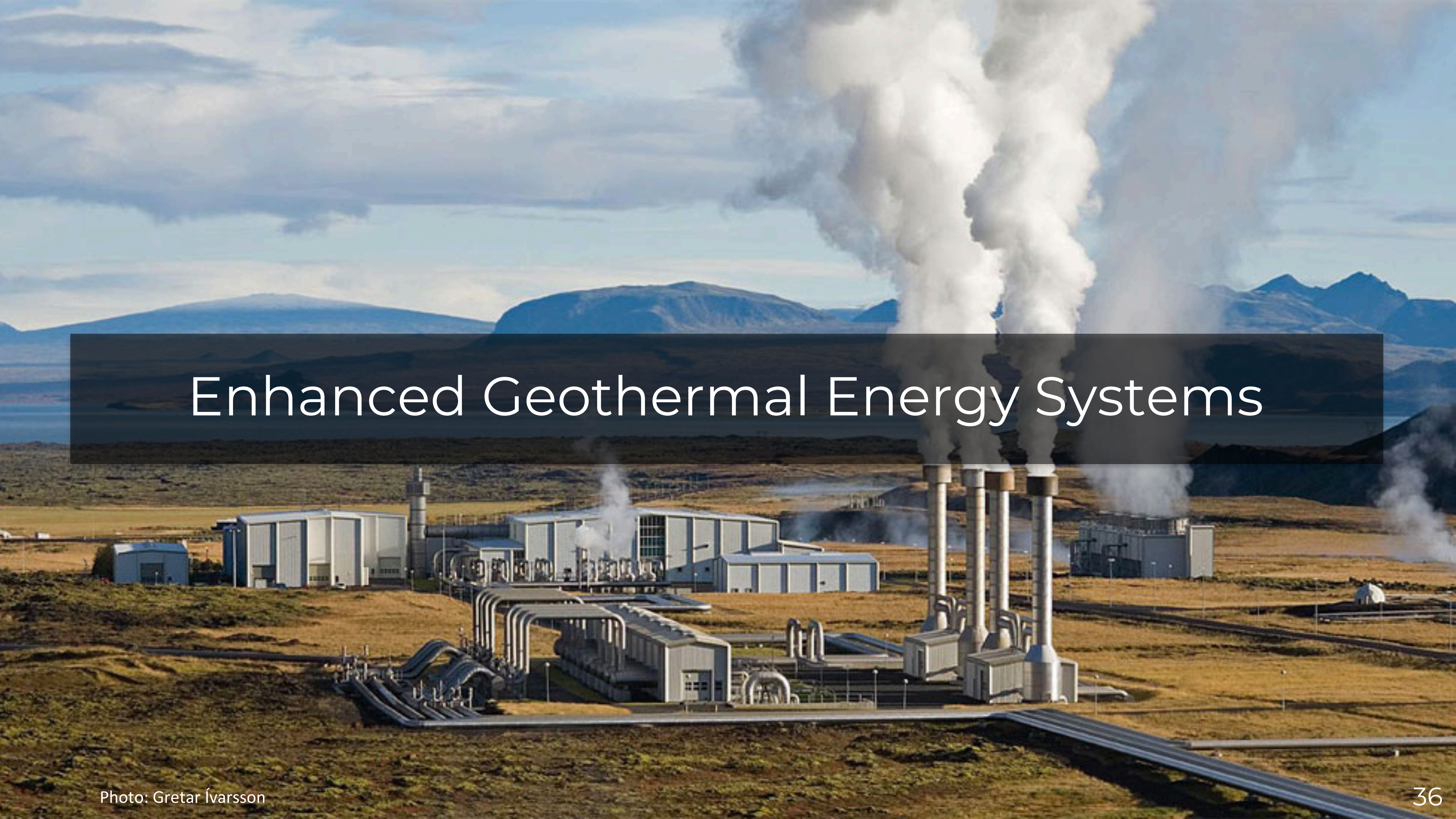


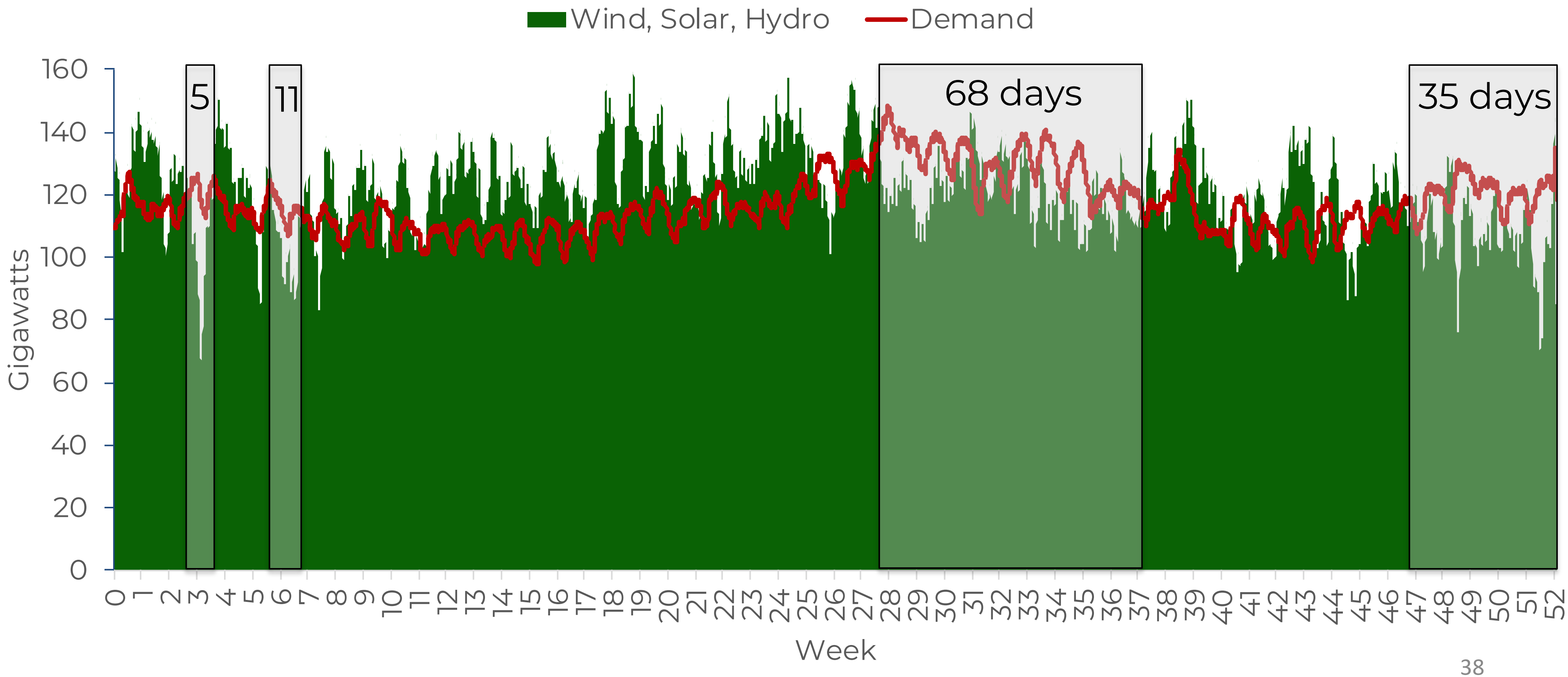
Photo: Gretar Ívarsson

What about storage?

The *Dunkelflaute* (“Dark Doldrums”)

Western Interconnection, Renewables + Storage Only

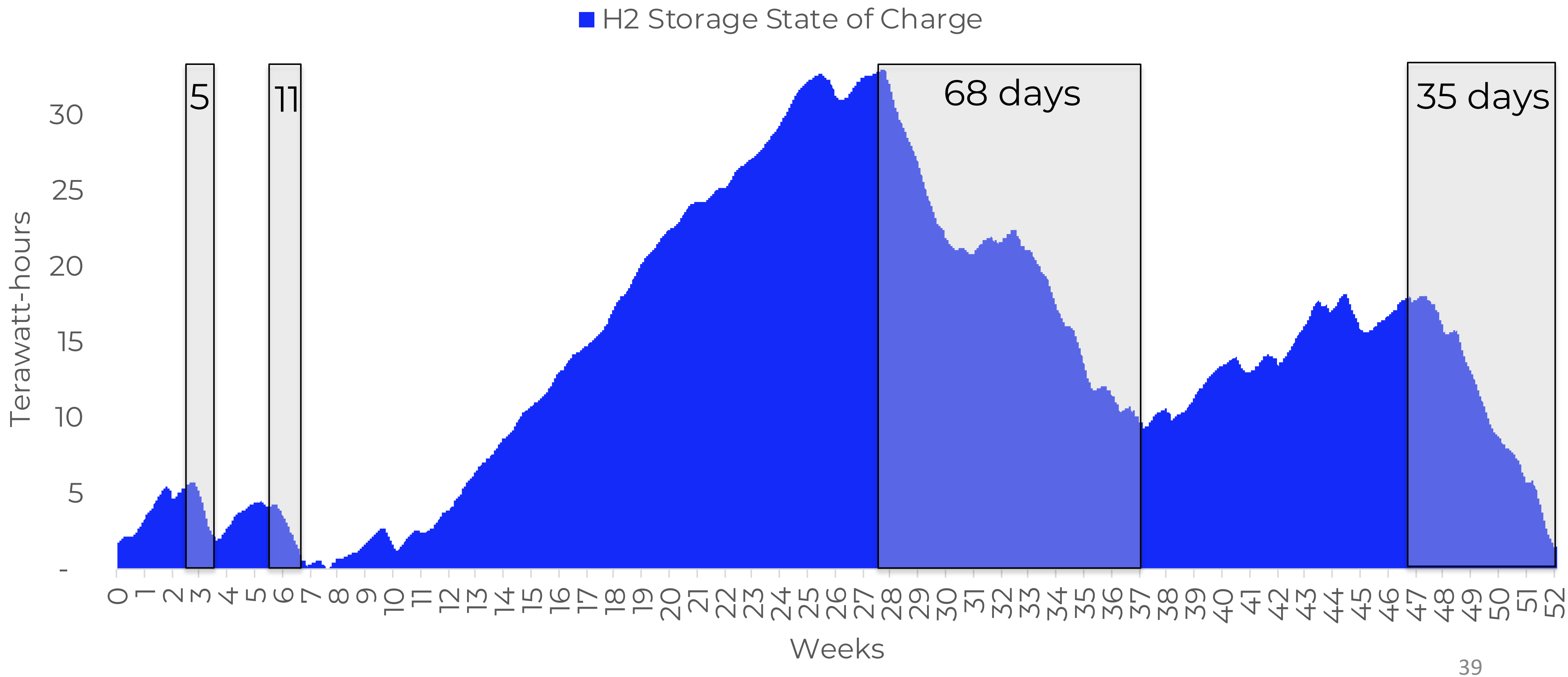
(24 hour rolling average power)



Long Duration Storage Needed for Renewables + Storage Only

Western Interconnection, 0 CO_2 emissions limit

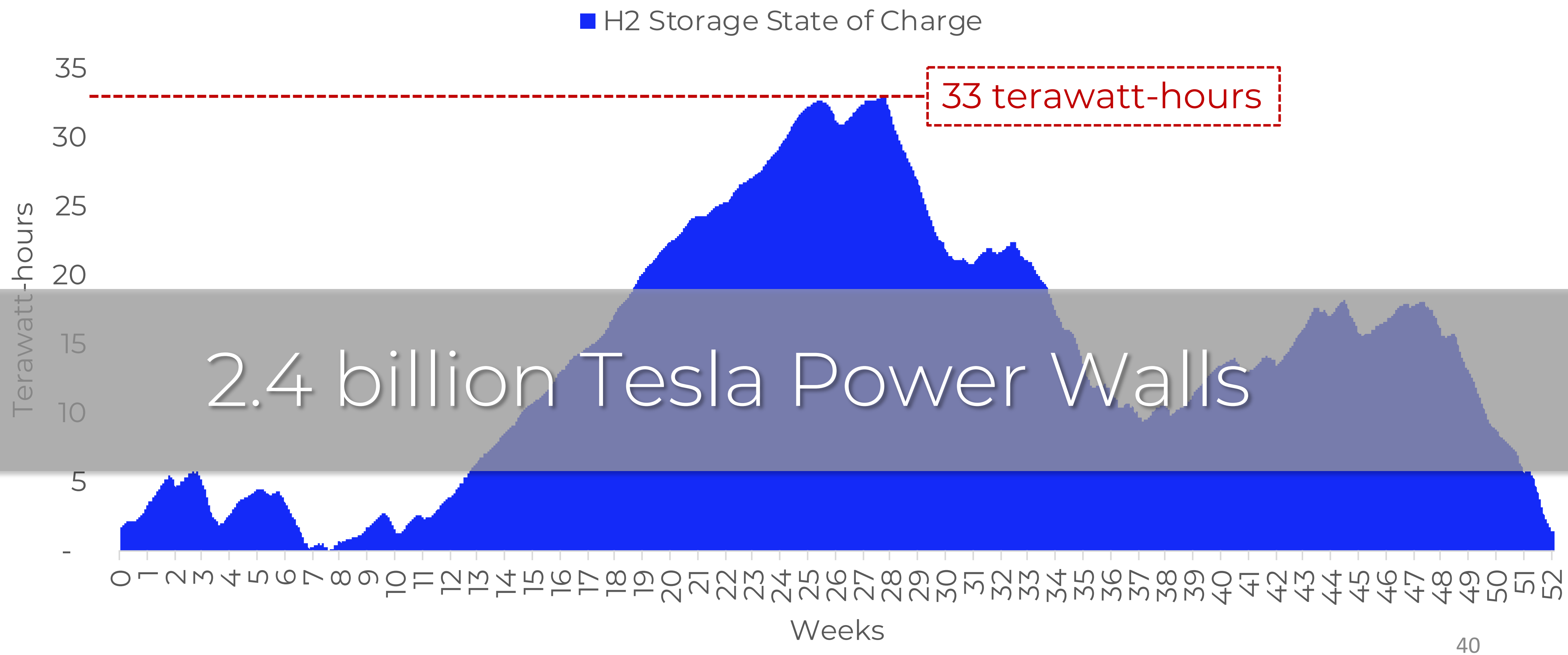
(24 hour rolling average power)



Long Duration Storage Needed

Western Interconnection, Renewables + Storage Only

(24 hour rolling average power)



Data source: Unpublished results, Jesse D. Jenkins, GenX model, Western Interconnection.

A very different kind of storage…

ENERGY STORAGE

Long Duration Breakthrough? Form Energy's First Project Tries Pushing Storage to 150 Hours

Minnesota utility Great River Energy will use new storage technology from the Bill Gates-backed startup to replace coal power with dispatchable wind.

JULIAN SPECTOR | MAY 07, 2020

ENERGY STORAGE

Utah Aims to Shatter Records With 1,000MW Energy Storage Plant

The one-of-a-kind facility would combine compressed air storage in salt caverns with hydrogen storage, large flow batteries and solid-oxide fuel cells.

JULIAN SPECTOR | MAY 30, 2019

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Linkedin.com/in/jessedjenkins

Google scholar: http://bit.ly/ScholarJenkins

RESOURCES

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Thank you for attending our webinar

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wleon@cleanegroup.org

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Wednesday, May 27, 2-3pm ET

Replacing New York City's Dirty Peaker Power Plants with Renewables and Battery Storage
Thursday, May 28, 1-2:30pm ET

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